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A Review of Greenhouse Technology in Agriculture

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ABSTRACT: Greenhouse Technology is the technique of creating beneficial environmental conditions for plants or crops, along with automation. While it's used primarily to protect plants from unfavorable climatic conditions, it's evolved to provide increased yields and reduced labor and resource costs. As a self-contained environment, greenhouses are easily controlled. Commercial growers now have a wide range of technologies to ensure the highest productivity levels with minimum labor.The modern smart greenhouse represents the convergence of sophisticated scientific know-how available from various software and hardware solutions. Greenhouse Controllers-Greenhouse environmental controllers deliver a high level of greenhouse management efficiency through automation, allowing growers to maximize their yields while lowering expenses. Smart motor controllers can open and close vents, turn on or off lights, all from the palm of your hands via smartphone apps. Controllers are pre-programmed with predetermined specifications based on criteria received from sensors located throughout the greenhouse. Let's dive into sensors. Sensors -Sensors throughout a greenhouse measure temperature, humidity, CO2, light, and VPD, WC, and EC so that your grow room controller can automatically adjust conditions to ensure your growing environment has the ideal conditions at all times. You'll spend less on labor and save hours by monitoring the dozens of variables that go into greenhouse management virtually through an app. The sensor feeds crop level data to an operating system that controls motors to open or close based on triggers. Now let's examine how automation brings it all together.Automation-By automating processes, growers can increase crop yields by ensuring a consistent environment and saving money by lowering energy use and decreasing labor costs. Better yet, this means growers have the time and energy to pursue business expansion, collaborations, or other interests. The internet of things (IoT) delivers a robust solution with sensor triggers and automation to fully complete the cycle. Data- Greenhouse controllers can track data over time, giving the grower insight into which combinations of irrigation, nutrition, lighting, and humidity promote the highest yields. Leveraged across multiple harvests, this data can help growers maximize their output while making effective use of resources and minimizing operating costs.

KEYWORDS: greenhouse, agriculture, technology, controllers, sensors, automation, data, costs

I. INTRODUCTION

Origin of life on earth explains the basic concept of greenhouse. Before origin of any living organism on the earth, the temperature of earth was around -18°C due to absence of atmosphere between earth and sun. Various gases namely nitrogen (N), carbon dioxide (CO_2), ozone (O_3), carbon monoxide (CO), oxygen (O_2), nitrous oxide (N_2O) etc.[1] available inside earth came out through spaces between plates of earth and formed a porous layer around earth, known as atmosphere. The newly formed atmosphere around earth had a unique property that it absorbed ultraviolet and far-infrared radiation coming from sun and allowed only short wave length (0.3-3 µm) radiation emitted by sun to reach the earth surface. Further, the atmosphere did not allow long wavelength (> 3.0 µm) radiation emitted by earth (Cengel, 1998). Hence, the trapped thermal energy raised the temperature of earth and air between earth and atmosphere. The rise of temperature of air is known as greenhouse effect. According to Encyclopedia 2000 (Anonymous, 2000) the greenhouse effect for environment is defined as:[2]

Greenhouse Effect - term for the role the atmosphere plays in insulating and warming the earth's surface. The atmosphere is largely transparent to incoming solar radiation. When this radiation strikes the earth's surface, some of it is absorbed, thereby warming the earth's surface. The surface of the earth emits some of this energy back out in the form of infrared radiation. As this infrared radiation travels through the atmosphere, much of it is absorbed by atmospheric gases such as carbon dioxide, methane, nitrous oxide and water vapor.[3]

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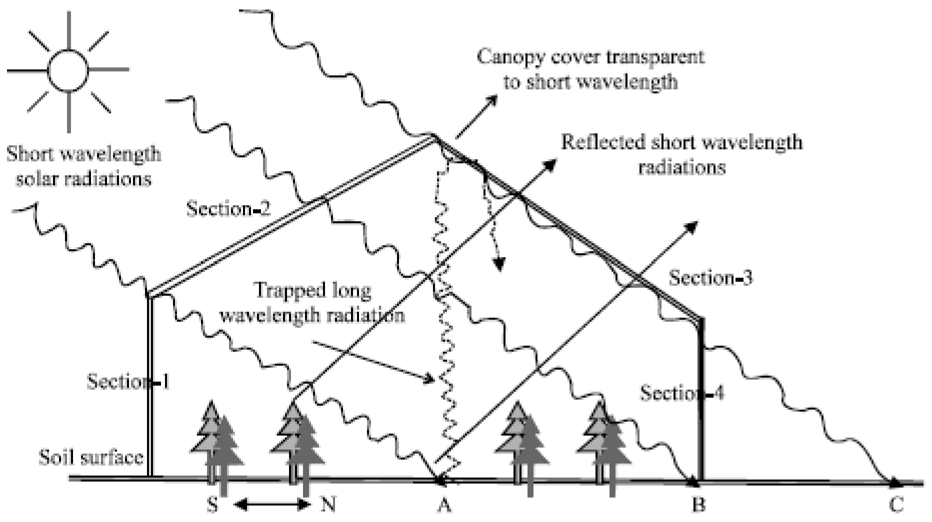

Fig. 1:	Greenhouse effect at micro level

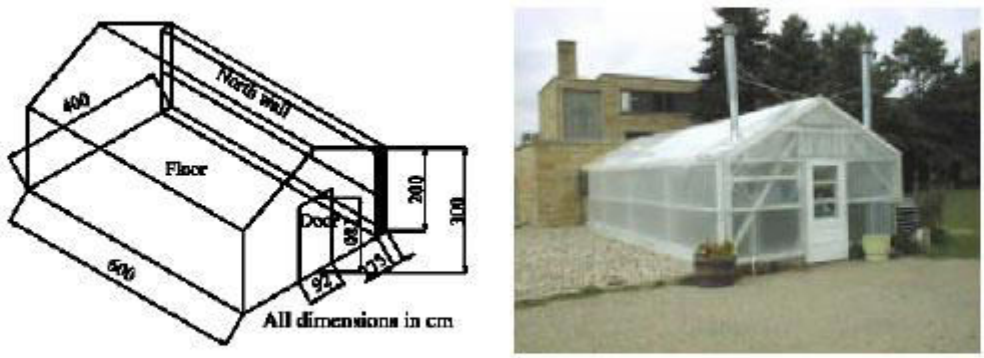

Fig. 2:	Isometric view of greenhouse and space heating

These gases then re-emit infrared radiation, some of which strikes and is absorbed by the earth. The absorption of infrared energy by the atmosphere and the earth, called the greenhouse effect, maintains a temperature range on earth that is hospitable to life. Without the greenhouse effect, the earth would be a frozen planet with an average temperature of about -18°C (about 0°F)".

Greenhouse

It is clear that for survival of living plants on the earth, there should be a favorable environment in terrestrial region controlled by short wave length radiation transmitted by the atmosphere. However, using the concept for optimum growth of living plants, a micro climate can also be created for maximum medicinal crops production in a controlled environment (Fig. 1).

Greenhouse is structure having the transparent walls and roofs (glass, FRP, polyethylene film) for maintaining suitable environment for the growth of plants, then this enclosure is called a greenhouse.[4]

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In rural areas a greenhouse can be use for crop production, crop drying as well as for space heating (for living of human being as well as for animals) as shown in Fig. 1 and 2, respectively.

Importance of Greenhouse Technology

Crop Production

Around 80% of the world population lives in the developing countries (Anonymous, 1995). Undoubtedly, the agricultural production must be increased to guarantee the food demand of the fast growing population. In the next 25 years around 50% more food has to be produced, mainly in developing countries (Brown, 1995).

India has attained the self-sufficiency in food and food products. The food grains production has increased from 50.8 million tones in year 1951 to 208.9 million tones in year 2000 (Anonymous, 2001a) whereas, the area has increased from 97.3 to 123.1 million ha under food grains over these 50 years. India accounts for nearly 10% of world production of fruit crops with annual production of about 44-46 million tones. India is the second largest producer of vegetables, next to China. In 1998-99, an estimated production of 87.5 million tones, accounted for 14.4% of the world production of vegetables.[5]

The country, now has reached a plateau in respect of area devoted to crop production . However, the population has increased from 361.1 million to around 1000 million in the past 50 years (1951-2000) (Anonymous, 2001b). The increasing population puts pressure on land and food. Thus sustaining the self-sufficiency in food is next challenge for scientists to think over. [6]The population-food imbalance can obviously be solved by increasing food production or by limiting the population. Another most viable solution to the food problem involves reducing the food losses, which occur during the food production, harvest, post harvest and marketing. In the developing countries, 10 to 40% of the crops harvested never reach the consumers due to poor post harvest management.Therefore, it is imperative to increase productivity as well as develop efficient post harvest handling technologies to combat post harvest losses of food to ensure the supply the food through the year.[7]

In the present scenario, to meet the worldwide demand of enhanced production, greenhouse cultivation could serve as a viable solution, facilitating off-season cultivation and protecting crop from unfavorable outdoor conditions. Apart from these, a greenhouse could be a better option for nursery raising, hardening of tissue culture plants, cultivation in regions which are prone to soil problems and extreme climates, also for cultivation of rare as well as medicinal plants.[8]

The demand of fresh as well as processed vegetables and cut flowers at Global level is also increasing in order to strengthen the export potential and economy of a country. But the cultivated area is decreasing due to construction of new roads, buildings particularly through urbanization and industrialization[9]. This calls for increasing productivity at a higher rate. The increased demand cannot be met through the traditional method of agricultural production. It necessitates improved and new alternative technologies to enhance production under normal as well as adverse climatic conditions and to bridge the gap between demand as well as existing production of vegetables, fruits and flowers.Greenhouse cultivation helps to create favorable microclimates where production of vegetables and flowers is made possible through out the year or part of the year as per the requirement. Greenhouse not only creates suitable environment for the plants but also encourages proper growth and fruiting as compared to open field cultivation. The greenhouse technology has also tremendous scope in horticultural sector, especially for production of hybrid seeds, high value vegetables, ornamental plants, medicinal plants, cut flowers and fruits, which fetch more prices in domestic as well as international markets[10]. The different processes of heat transfer occurring inside the greenhouse during crop cultivation are shown in Fig. 3.

Crops/Fruit Drying

Open sun drying (OSD) is the most primitive crop drying, under which the solar radiation falls directly on the crop surface and it is absorbed. The absorbed radiation heats the crop and evaporates the moisture from crop.[11]

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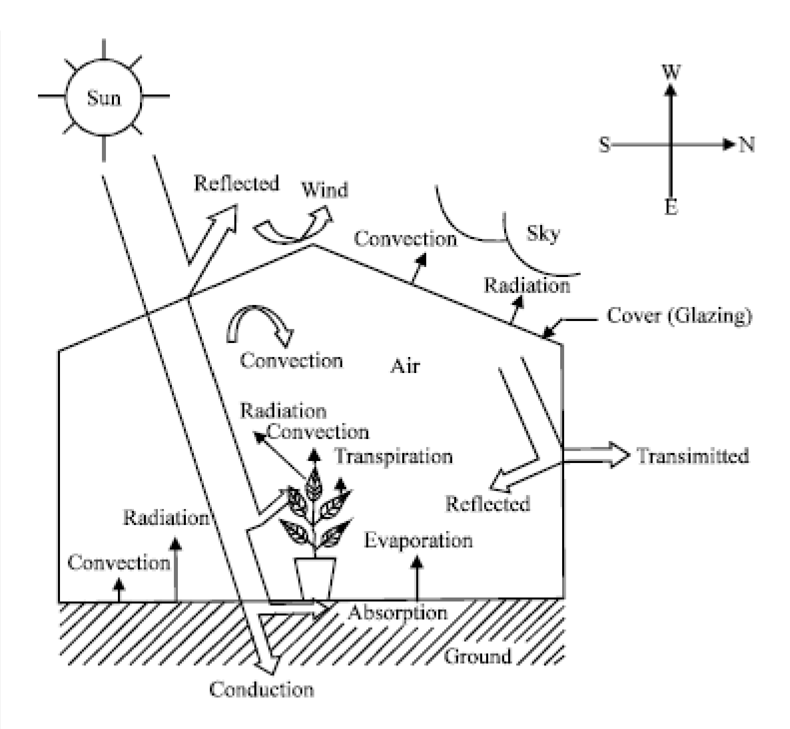

Fig. 3: Energy flow processes in greenhouse system

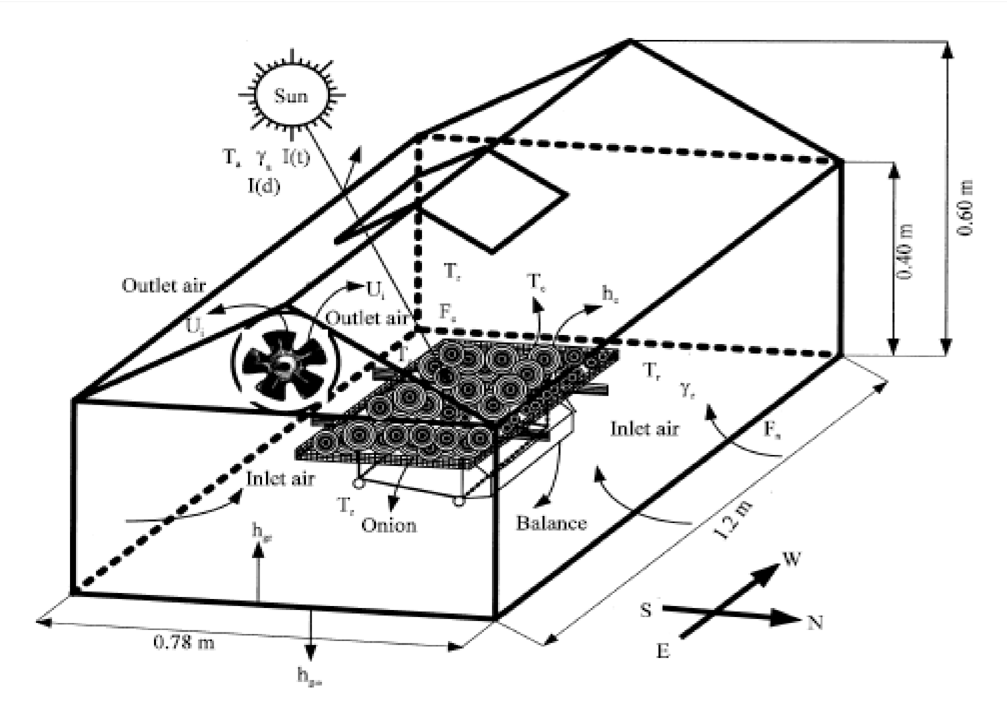

Fig. 4: Schematic view of greenhouse dryer

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During this process, the amount of solar energy received at the crop surface is lost at various stages through reflection, radiation, convection and conduction. Also the quality of the product is lowered significantly. In general, open sun dried products do not fulfill the international quality standard and therefore can not sell on international markets [11]

Greenhouse systems can play a vital role in post harvest drying of crop produce. The greenhouse drying technology produce good quality product over open sun drying [12] This highlights that the comprehensive understanding of greenhouse effect is important to enhance production and drying of crops. Figure 4 shows the principle of greenhouse crop drying. In this case too, microclimate is created inside the greenhouse. Solar radiation incident on the glass cover is transmitted inside greenhouse after reflection from the glass cover. Further, a part of transmitted radiation is reflected back in the form of short wavelength from the surface of the crop, which is again transmitted to atmosphere through the glass cover. The remaining part is absorbed by the surface of the crop. Due to the absorption of solar radiation, the crop temperature increases and the crop start emitting[13]

•	Long wavelength radiation, which is not allowed to escape to atmosphere due to presence of glass cover unlike open sun drying. Thus the temperature above the crop inside greenhouse becomes higher,
•	The glass cover serves one more purpose of reducing direct convective losses to the ambient which further becomes beneficial for rise in crop and greenhouse air temperature respectively[14]
•	The convective and evaporative losses occur inside the chamber from heated crop simultaneously. The moisture (the vapour formed due to evaporation) is escaping through air vent provided at the roof for natural convection and for forced convection a fan is provided on the sidewall of the greenhouse as shown in Fig. 4.

II. DISCUSSION

Classification of Greenhouse System

Greenhouses may be classified on the basis of several criteria as given below:

Based on the Material Used

•	Glass house
•	Plastic film greenhouse
•	Rigid panel greenhouse

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Based on the Shape of the Cover
Greenhouses are available in various shapes and sizes (Tiwari, 2003).

•	Spherical dome
•	Hyperbolic paraboloid
•	Quonset
•	Modified Quonset (Modified IARI model)
•	Gothic arch
•	Mansard roof
•	Evenspan
•	Unevenspan
•	Vinary
•	Modified arch

Shapes of greenhouses of are described in Fig. 5. The evenspan greenhouse is most common in application. Therefore an evenspan greenhouse has been chosen for the present study.

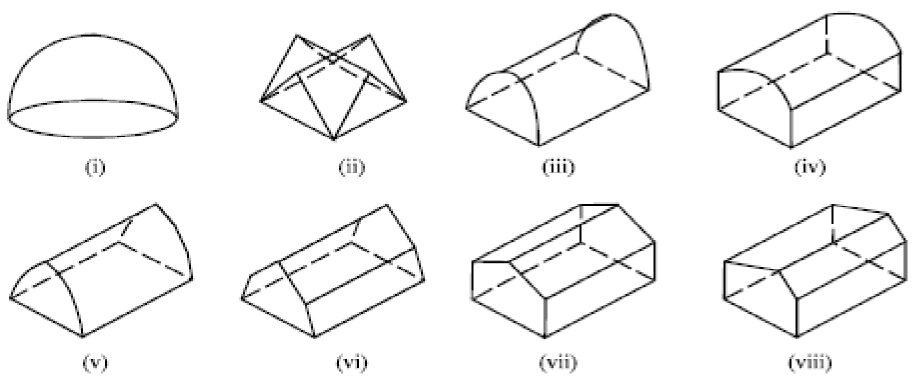

Fig. 5:	Classification of greenhouse on the basis of shape; (i) Spherical dome, (ii) Hyperbolic paraboloid, (iii) Quonset, (iv) Modified Quonset, (v) Gothic arch, (vi) Mansard roof, (vii) Evenspan and (viii) Unevenspan

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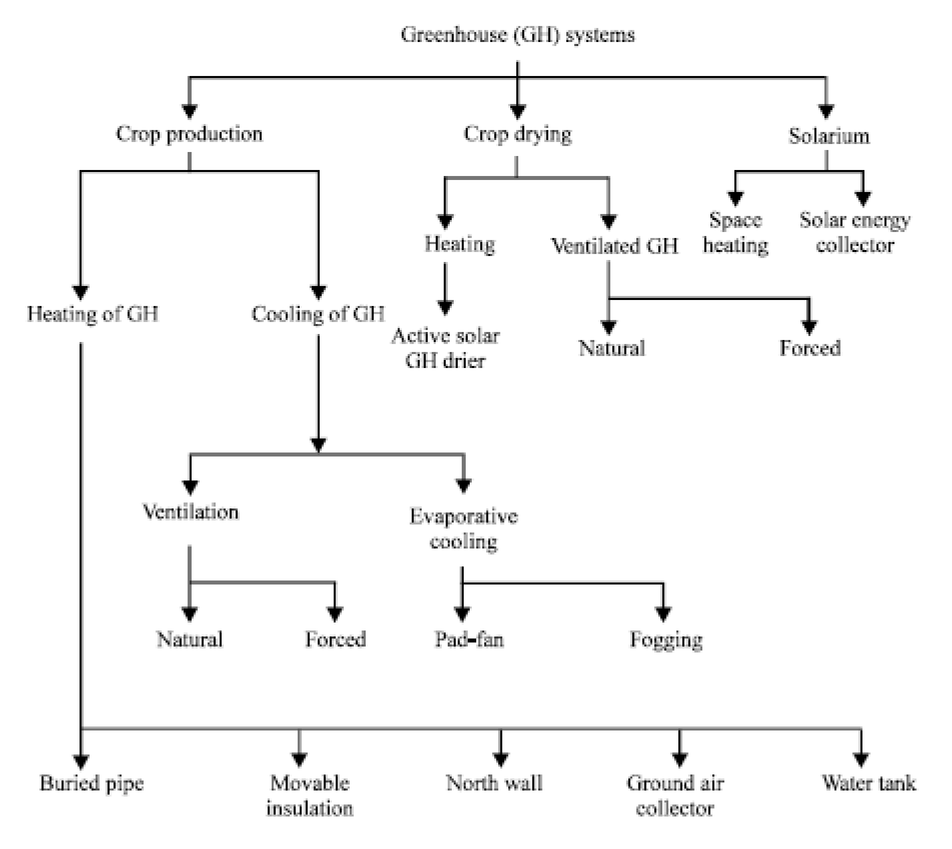

Fig. 6:	Classification of greenhouse systems

Based on Cost Factor or Technology Involved

•	Low cost / Low-tech greenhouse.
•	Medium cost /Medium - tech Greenhouse
•	High cost / Hi-tech Greenhouse[15]

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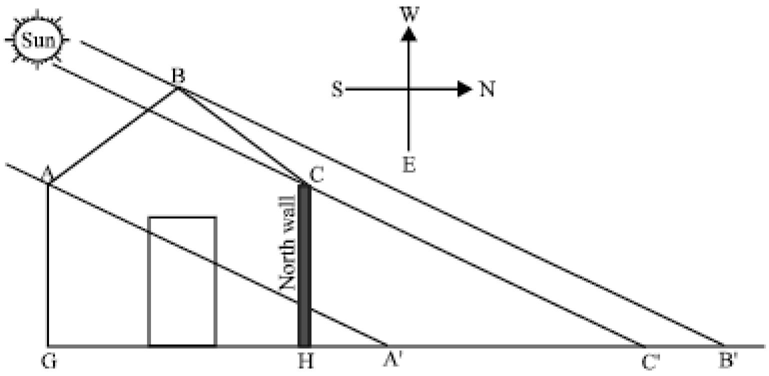

Fig. 7: Schematic view of greenhouse showing numerator and denominator of north-wall for south-roof of a greenhouse

Based on Application of Greenhouse Systems

On the basis of working and principal applications, greenhouse may be broadly classified in the three categories: (i) greenhouse for crop cultivation, (ii) greenhouse for crop drying and (iii) greenhouse as the solar energy collector. The detailed classification on this basis is shown in Fig. 6.

Selection of Greenhouse

The design of a greenhouse depends upon the latitude of the place and the requirement of crop. The main criteria for selection of greenhouse can be its value of solar fraction.[16]

Solar Fraction

The concept of solar fraction is very important in thermal analysis of a greenhouse system. It gives an idea regarding the distribution of solar radiation on walls and floor of greenhouse as compare to total incoming solar radiation. When the incoming short wavelength solar radiations, falling on one section of a greenhouse, intercepts the other side (internal) of the greenhouse before falling on to ground; it passes through the canopy cover of that side because it consists of short wavelength only (Fig. 1). Whenever solar radiation falls on a section, after absorption, reflection and transmittance by canopy cover, the rest of the radiation either falls on the ground or on the internal side of any other section[17]. For an east - west oriented greenhouse, solar fraction for north wall is defined as the fraction of total radiation falling on north wall (Fig. 7).

For an east-west oriented greenhouse particularly in northern hemisphere, solar radiation that falls on the north wall is transmitted to atmosphere through the glazed cover. This becomes a loss especially during the month of winter, for area falling on the north of north tropic sun line. For efficient design of greenhouse under the above condition, it is necessary to make the glazed north wall opaque. Solar radiation transmitted through north wall can be retained and utilized by constructing north brick wall [18]It is required to incorporate the effect of solar fraction for north wall of an east-west oriented greenhouse in developing its thermal model.

The solar fraction for north wall is defined as follows:

$$F_n = \frac{\text{Solar radiation available on north wall inside the greenhouse for a given time}}{\text{Solar radiation measured on the north wall and floor of the greenhouse for same time}}$$

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For a six-section greenhouse (Fig. 7), mathematically it can be expressed as follows:

$$F_n = \frac{(F_{n1} + F_{n2} + F_{n3} + F_{n4} + F_{n5} + F_{n6})}{(F_{n1} + ...F_{n6}) + \{(1 - F_{n1}) + (1 - F_{n2}) + (1 - F_{n3}) + ...(1 - F_{n6})\}} \quad (1)$$

or,

$$F_n = \frac{(F_{n1} + F_{n2} + F_{n3} + F_{n4} + F_{n5} + F_{n6})}{6} \quad (2)$$

The above equation can be rewritten as follows:

$$F_n = \frac{\sum_{j=1}^{6} F_{nj}}{6} \quad (3)$$

F_n on north wall due to south wall = HA'/GA'
F_n on the north due to south roof = A'C/A'B'

Greenhouse can be used for crop production as well as for drying of crop/fruit/medicinal plants of high economic value. It has tremendous scopes in space heating for human and cattle. Solar fraction of a greenhouse can be sole criteria for selection of greenhouse. For thermal heating of the greenhouse the solar fraction should be minimum.[19]

III. RESULTS

The food crops and cash crops grown the world over are mostly grown in open fields, but there's a tiny five percent that are grown under controlled and predictable conditions, precisely for the purpose of a harvest that can be more accurately estimated. And this is made possible through the use of greenhouse technology. In short, green house technology is a technique of providing favourable environmental conditions to plants by growing them a greenhouse, a structure with walls and roof made mainly of transparent material, such as glass.[20]

These structures could range in size from small sheds to industrial-sized buildings. Exposed to sunlight, the greenhouse becomes significantly warmer than the external ambient temperature, protecting its crops from extreme weather – not only wind and temperature but also precipitation and pests. In this way, a greenhouse creates an ideal microclimate around the plants that support their optimal growth. The temperature and humidity within are regulated through ventilation. Thus, overall, greenhouses allow for much greater control over the growing environment of plants.[21]

Advantages of Greenhouse Technology.

There are several advantages to utilizing greenhouse technology. For example, crops grown under such controlled conditions provide a yield that is 7 to 12 times higher than crops grown in the open. Besides the fact that quantity of produce can be better estimated, it also provides for year-round and off-season production. Moreover, this technology helps produce disease-free and genetically superior transplants. It also aids the efficient use of chemicals and pesticides to control pests and diseases. Water requirement is limited and easy to control.

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All these advantages have ensured that more than 50 countries have jumped on the bandwagon of greenhouse farming, taking it up on a commercial scale. However, the design of greenhouses and the total area under cultivation are variable, depending on local conditions. Taking a look at world statistics in greenhouse farming, the United States has a total area of 4000 ha under greenhouses, used mostly for floriculture with a turnover of more than 2.8 billion per annum. In Italy and Spain, greenhouses are mainly being used for growing vegetables like capsicum, beans, tomatoes, strawberries and watermelons.[22]

Greenhouse Methods: These greenhouses use simple, tunnel shaped structures with polyethylene film as cladding, cutting out any elaborate environmental control equipment. In Canada, greenhouses are used both for flower cultivation and off-season vegetable cultivation. The vegetables typically include tomatoes, cucumbers and capsicum. When it comes to greenhouse-grown flowers, the Netherlands stands at the top as the traditional exporter of greenhouse-grown flowers and vegetables. The Netherlands is also the country with the most advanced greenhouse industry in the world and also upholds a strong R & D component. In the Gulf countries, [23] greenhouses are developed to help grow crops under extreme climatic conditions. Israel is the largest exporter of cut flowers and has a wide range of crops under greenhouses. Even Turkey has an area of 10,000 ha under cover for cultivation of cut flowers and vegetables. Egypt has about 1000 ha greenhouses consisting mainly of plastic covered tunnel type structures. In Asia, Japan and China are the largest users of greenhouses.[24]

The pace of development of greenhouse technology has been faster in China than anywhere else in the world. Japan has more than 40,000 ha under greenhouses out of which nearly 7500 ha is devoted only to fruit orchards. South Korea too has more than 21,000 ha. Thus we can see how greenhouses permit crop production in areas where winters are severe and extremely cold as in Canada and USSR, and also permit production even in areas in which summers are extremely intolerable as in Israel, Kuwait and the UAE. Greenhouses in Philippines make it possible to grow crops in spite of excessive rains and also in moderate climates.[25]

The greenhouse industry set off with a modest beginning almost half a century ago, although as an idea it had existed since Roman times. Greenhouses in which the temperatures could be manually manipulated first appeared in 15th century Korea. It later appeared in the Netherlands and then England in the 17th century. Experimentation with the design of greenhouses continued during the 17th century in Europe, as technology produced better glass and construction techniques improved. The greenhouse at the Palace of Versailles was as example of their size and elaborateness. Its golden era was in Victorian England where the largest glasshouses yet were conceived.[26]

From being a concept that is fancy or a structure that is elaborate and that adorns palaces and gardens in classical Europe, in the present day, it is also aiding farmers out of poverty. A start-up called Kheyti in Telangana, India, recently won the global social venture competition. Kheyti produces and markets ‘greenhouse in a box’ – a simple, low-cost greenhouse that can sit on a small area of farm. This has enabled the farmers to grow regular crops, which guarantees them year-round income even if everything else goes wrong. These are farmers for whom income variability is the biggest problem, with only two harvests a year.[27]

This income too is under attack by various environmental factors, including unseasonal rain and pest attack. These destroy the crop time and again, and keep farmers stuck in the poverty cycle. The typical greenhouse available in India was originally designed for farmers in developed countries who grow high value flowers or vegetables – well out of the price range of a low income farmer. The new greenhouse is simpler, with fewer materials and a smaller footprint that’s roughly half the size of a basket-ball court or 2% of the land area of a typical farm in India. The layers of shade netting on the top reduce the temperature inside by 5-8 degree C. Insect netting on all sides reduces pest attack by 90%. A profitable harvest, of course, needs more than a greenhouse. A drip irrigation system, coupled with shade that reduces heat and evaporation, helps cut water usage by 90%. They also need access to right seeds and fertilizers to be used inside, and the right training needed to manage any disease. Since a greenhouse can protect crops from floods and pests, the farmers are able to grow seven times more produce. All this goes to show that a greenhouse is a worthwhile investment that can stabilize both environmental conditions and generate income through the year.[28]

IV. CONCLUSIONS

Six innovations are shaping the future of greenhouse farming

THEY definitely don't capture the headlines in the same way as vertical farms, but greenhouses still play a vital role in global food production.Having helped to cultivate indoor crops for thousands of years, it's safe to say this age-old growing technique will be around for a few years yet.Thanks to advances in technology, the humble glasshouse can now be transformed into a precisely-controlled growing environment that farmers can rely on to achieve improved

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yields and profits.At CambridgeHOK, we're proud to have been appointed as the build partner for Beeswax Dyson Farming - Britain's biggest privately-owned farming business - for a new multi-million-pound state-of-the-art indoor strawberry production facility.In terms of its size, complexity, sophistication and green credentials; the Lincolnshire development will be the first of its kind in the UK horticulture market.[29]
As the 'buy local' trend continues to grow, we're sure the technology used on this project will soon be replicated by growers across the UK.In this article, we'll outline all the biggest benefits that modern technology can now bring to the greenhouse industry.

What greenhouse farming technologies are there.

1. Intelligent automation
Automated irrigation systems, pH sensors and climate control software can all be used to solve common problems faced by indoor farmers, such as disease prevention and pest management.

By using wireless sensors, it's possible to accurately monitor real-time temperatures (and fluctuations) to maintain an optimum growing environment. Depending on the fruit or vegetables you want to produce, this could be the difference between a seasonal yield or year-round production.At CambridgeHOK, we can provide user-friendly integrated automation solutions to increase efficiency, profit and sustainability.Alongside this we regularly install automated solutions to move plants/product across the site through automated vehicle or benching solutions. Across larger sites we are seeing excellent returns on investment for this type of technology.[30]

2. Self-sufficient water systems
When it comes to water usage, most glasshouses can become self-sufficient if the right rainwater harvesting system is put in place.Instant automatic irrigation systems can then reuse this water when and where it's most required. We also work hard to ensure no water is lost in the growing process by collecting internal condensation and recirculating any water from the irrigated plants. This also means we can reduce fertiliser costs as nothing is lost.

3. Optimised lighting levels
Light is obviously the most critical component for indoor growing, but most commercial greenhouses rely solely on sunlight to maintain the right environment.When considering lighting in a crop, it's important to consider more than simply the intensity of light required. Different lighting spectrums can play an important part in the plant's growth, with different spectrums able to influence many factors such as crop speed, plant rooting and even taste.

4. Cooling technology
Although this technology is used more sparingly by greenhouse growers, some do employ innovative cooling systems to achieve optimum air and circulation levels - creating the perfect growing environment for their produce.If a heating, cooling or CO2 solution is required, we can offer a complete turn-key solution.

5. Strategic shading
Commercial glasshouses can now create the perfect growing environment with a series of strategically-placed flame retardant screens to provide UV and thermal shading. Depending on the crop being grown, this could save up to 60% in energy consumption.To maximise environmental control, we specialise in providing screens and air ventilations systems which allow growers to enjoy optimum conditions without compromising on quality.

6. Combined Heat & Power (CHP) systems
In years gone by, the only thing you had to do after building a commercial glasshouse was fill it with crops and wait for them to grow.Now, the heat which is generated onsite can be converted into energy to sell off, store or use to power the technology inside the glasshouse - through a specially-built Combined Heat & Power (CHP) system.Not only can this provide major energy savings, it can also help to enhance the growing environment and provide a consistent crop.

Why adopting greenhouse technology is vital

There's no doubt the greenhouse industry is continuing to evolve at breakneck speed.With the global demand for food only expected to grow in future, it looks as if it will become increasingly important for control environment growers to make full use of the resources available to them.At Cambridge HOK, we don't just construct commercial scale glasshouses – we educate growers and investors about the technology they could adopt to enjoy the very best operational performance.[31]

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Using our expertise and in-depth knowledge of automated climate control and energy systems, we advise about all the options available and tailor the design to suit individual growing requirements.[31]

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