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Development and Performance Evaluation of Automatic Side Curtains Rolling Mechanism for Polyhouse

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ABSTRACT: In naturally ventilated greenhouse, trapping heat and CO₂ and reduction of temperature is achieved by unrolling and rolling of side polythene curtains for inside environment control. Traditionally, rolling and unrolling of curtains are carried out manually by using universal joint and crank mechanism. This manually operated curtain system comes with several disadvantages like break down of system due to rusting, difficulties to lock or unlock system, uneven rolling of curtains, time consuming operation, etc. Therefore, the attempts were made to design and development mechanism for operation of curtains in greenhouse. The curtain operating mechanism consists of single DC gear motor used for rotating both side curtain roller pipe in clockwise and anticlockwise direction to roll up and roll down the curtains respectively. This is achieved by connecting both sides curtain roller pipe with the help of bevel gears. This mechanism fitted with automatic control system which operates curtains on the basis of the inside temperature of greenhouse.

The study found that the average maximum temperature rise inside naturally ventilated greenhouse was 9°C and 3.7°C when curtains were fully closed and fully open condition respectively at ARDF Tansa, Tal. Wada, Dist. Palghar. It was also found that the average maximum temperature rise inside naturally ventilated greenhouse was 8.2 °C and 4.1°C when curtains were fully closed and fully open condition respectively at CAET Research Farm Dapoli. When automation was provided to the curtain roll up and roll down mechanism, it was found that when inside temperature of greenhouse prototype reaches to the higher limit temperature (32 °C) the curtains were opened. These curtains were remained open until the inside temperature of greenhouse prototype goes below or equal to the lower limit temperature (28 °C).

KEYWORDS: Automation, curtains, naturally ventilated greenhouse, mechanisation, temperature.

I. INTRODUCTION

Agriculture is the backbone of our country's economy, which accounts for nearly 30 per cent of GDP and employs 70 per cent of the population. Though this is a rosy picture of our agriculture but how long will it meet the growing demands of the ever-increasing population, if we rely only on traditional farming. Agricultural technology available since 1940s couldn't meet the demand of food for today's population [2]. The forthcoming demand and challenges could be satisfied by diverting towards protected cultivation for revolutionizing agricultural productivity.

In open field cultivation that is traditional method of farming, there is no control over the environmental parameters like temperature, relative humidity, light intensity etc. Due to uncontrolled environment the changes in climatic lead to disease or pest attacks, eroding soil condition etc, thus, the production and quality of crop decreases. Also, the water requirement for crop is high in open field cultivation.

Protected cultivation practices can be defined as a cropping technique where within the micro environment surrounding the plant body is controlled partially or fully as per plant need during their period of growth to maximize the yield and resource saving [6]. Greenhouse is the most practical method of accomplishing the objectives of protected cultivation [5].

The utilization of greenhouse technology started in India during 1980s mainly for research activities, after India had achieved self-sufficiency in food grain production. India's first exposure to hi-tech protected farming of

vegetables and other high-value horticultural produce came through the Indo-Israel project on greenhouse cultivation, initiated at Indian Agricultural Research Institute (IARI), New Delhi in 1998 [4].

Greenhouse automation is all about an efficient, accurate and modern intensive agriculture, which judiciously utilizes all available natural resources, recycles the data and resources within the system, and claims higher productivity, higher returns, better quality while remaining environment friendly. Development of an automatic greenhouse system that's low-cost, operating with minimum human intervention, accurately ready to maintain its set points, able to learn and adjust itself have been a number of the very obvious interests on which investigators are working to satisfy economic, environmental, market, industrial and human-preference needs.

Konkan region comes under hot and humid region. The annual average temperature during winter is in range of 20-30 °C while in summer it is 32-40 °C and high relative humidity present in all season. The Konkan region falls under heavy rainfall. The annual average rainfall is in range 2500 mm to 4500 mm [3]. This condition is favorable to production of most of the crop. High rainfall during rainy season provide favorable condition for paddy crop only, but other high value vegetable crops could not be cultivated by the farmers in open field, because open field cultivation system did not allow any flexibility of growing crops. The most of farmers in Konkan region are small and marginal farmers, thus small naturally ventilated polyhouses are popular in Konkan.

In naturally ventilated greenhouse during night time it is necessary to trap heat and CO₂ for better growth of crop, while during day time the temperature of naturally ventilated greenhouse goes beyond the optimum limits suitable for the crop. Trapping heat and CO₂ and reduction of temperature is achieved by unrolling and rolling of side polythene curtains. Traditionally rolling and unrolling of curtains are carried out manually by using universal joint and crank mechanism. This manually operated curtain system comes with several disadvantages like break down of system due to rusting, difficulties to lock or unlock system, uneven rolling of curtains, time consuming operation, etc. Therefore, the attempts were made to design and development mechanism for operation of curtains in greenhouse.

II. MATERIALS AND METHODS

Fabrication of prototype greenhouse structure

The design of curtain rolling mechanism for existing greenhouse was carried out. To test feasibility of designed and developed mechanism, scale reduction of existing structure was constructed. The naturally ventilated greenhouse prototype of 1.22m × 0.65 m × 1.22 m was constructed. The detailed dimensions are shown in figure 1.

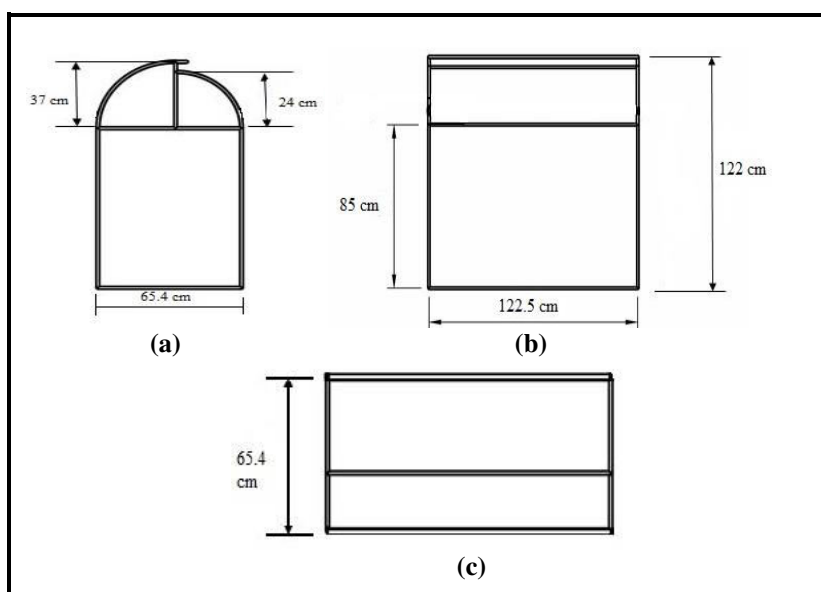
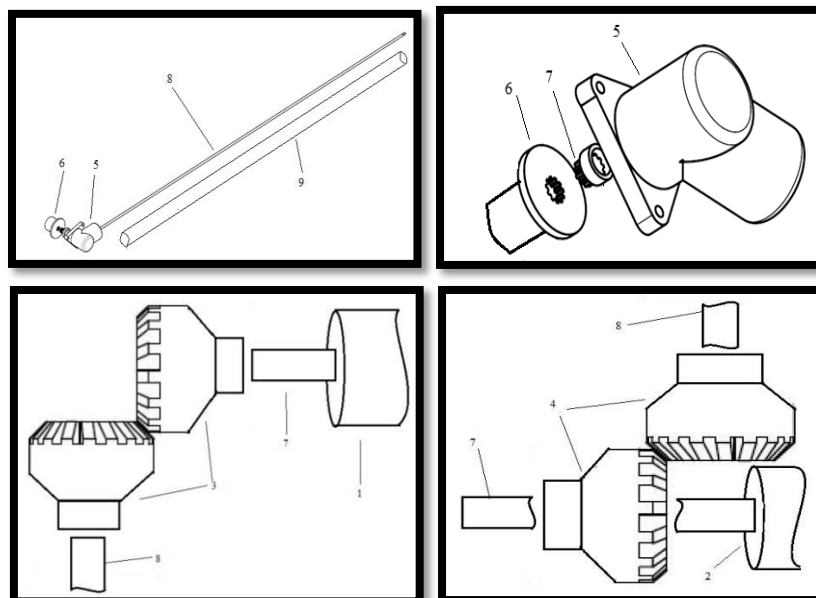


Fig 1: Front, side and top view of prototype naturally ventilated greenhouse

Design consideration of mechanism for curtain operating system



1- Curtain roller pipe, 2- Opposite side curtain roller pipe, 3- Bevel gear (connected to the curtain roller pipe 1), 4- Bevel gear (connected to the opposite side curtain roller pipe) 5 – Gear housing, 6- Coupling, 7- Shaft, 8 - Connecting rod, 9- Hollow pipe

Fig 2: Schematic view of curtain rolling mechanism

As shown in figure 2 various parts or components were used to develop the mechanism. Mechanism consists of a DC geared motor which was fixed on one side of the structure was connected to the one end of curtain roller pipe. Curtain roller pipe was placed inside the bearing which was fixed on lower arch of structure with the help of bearing housing. At the another end of curtain roller pipe bevel gear was fixed with the help of coupling and shaft on which bevel gear was placed. This bevel gear was placed inside the gear housing. Another bevel gear was connected to the opposite side curtain rolling pipe with the help of gear shaft. This gear was placed inside the gear housing, which was fixed on the structure. The direction of bevel gear which is connected to another curtain roller pipe was opposite to that of the bevel gear which was connected to the first roller pipe to achieve the opposite direction of revolution. These both bevel gears were connected by the connecting rod which was aligned in hollow pipe with the help of guide.



Fig 3: View of curtain operating mechanism

Selection of DC gear motor for prototype greenhouse

Table 1 shows factors to be considered and calculated values of required terms while selection of motor for naturally ventilated greenhouse prototype.

Table 1 Factors to be considered for selecting gear motor for greenhouse prototype

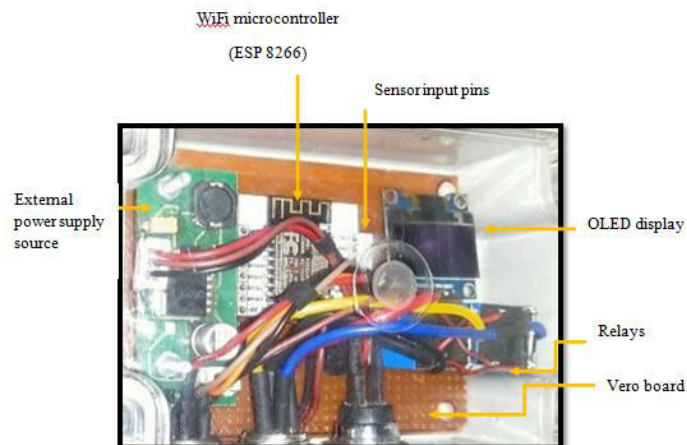
Sr. No.	Items	Specification
1.	Weight of curtain support pipe	1.150 kg
2.	Diameter of curtain roller pipe	21.6 mm
3.	Curtain roll up height	70 cm
4.	Weight of curtain (polyethene)	0.190 kg
5.	Total weight of both sides of curtain support pipe and curtain (polyethene)	2.680 kg
6.	Speed of motor	20 rpm
7.	Circumference of roller pipe	6.78 cm
8.	Revolution of roller pipe to roll up to maximum height	11 revolutions
9.	Time required for curtain roll up	33 seconds
10.	Force required for roll up the curtain	26.29 N
11.	Work done	18.4 J
12.	Power required to roll up curtain	0.6 watt
13.	Torque required to roll up curtain	0.284 Nm

The minimum power and torque requirement of motor for greenhouse prototype was found to be 0.6 watt and 0.284 Nm respectively. The 15 watt motor having 2.94 Nm torque was selected as per availability.

Automation of the curtain operating mechanism

Hardware

The automatic curtain operating system consists of different hardware such as microcontroller (WiFi module), temperature and humidity sensors, internal power supply, relays, display, etc. and assembled together as a unit of automatic curtain control system as shown in figure 4.

**Fig 4: View of automatic curtain control system**

The figure 5 shows that to the input section different components like battery for power supply, reset/ push button and sensor were connected to pass the field data to micro controller for processing. At output section of micro controller display, relays and limit switches were connected for control the operation of curtain system.

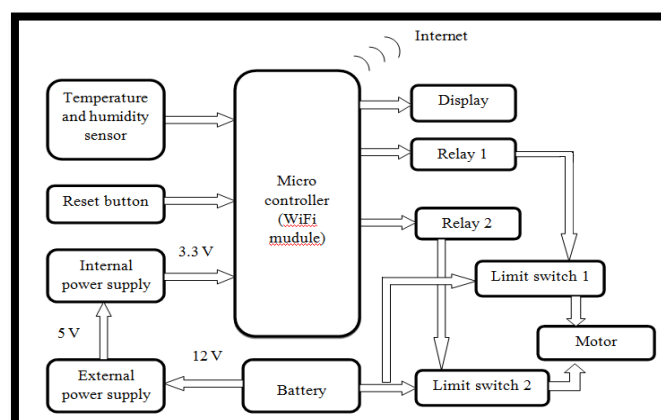


Fig 5: Block diagram of hardware connections of curtain control system

Steps for automation of the curtain operating system

The temperature and humidity sensor was installed in the greenhouse prototype. The smart phone was connected to the system for setting the lower and higher set point. The temperature and humidity sensors is continuously sensing the temperature and humidity of air and sending the data to the microcontroller. The microcontroller sends the signal to the relay to ON/OFF depending upon the determined set point of temperature which controls the starting and stopping of motor with the help of limit switches. Also, the data is sent to the server if continuous WiFi is provided to the microcontroller. The required programming was done on the Arduino platform. The pictorial view of the controller is shown in the Figure 4.

Working of the automatic curtain operating system

1. The automatic curtain control system maintains optimum temperature and humidity favourable for the crop inside the greenhouse prototype by rolling and unrolling of curtains.
2. The power supply was given to the controller. After connecting power supply, the sensor provides values of temperature and humidity continuously to the controller.
3. As the temperature inside the greenhouse prototype goes beyond the higher limit value of temperature or below the lower limit value, the microcontroller operates relays.
4. Relays further control the limit switches and power supply which results in starting or stopping of motor.
5. As temperature goes above high limit, the motor start to roll up curtains of both sides at the same time, which allows ventilation for greenhouse, and if temperature goes below lower limit point the motor start to roll down the both side curtains for trapping heat and CO₂ inside the greenhouse.

Details of developed mechanism of curtain operating system

Table 2 shows specifications of developed curtain operating mechanism of greenhouse prototype.

Table 2 Specifications of curtain operating mechanism of greenhouse prototype

Sr. No.	Item	Specifications
1.	Size of greenhouse prototype	1.225 m × 0.654 m
2.	Ridge height	1.22 m
3.	Gutter height	0.85 m
4.	Top vent height	0.13 m
5.	Curtain roll up height	0.70 m
6.	Diameter of curtain roller pipe	21.6 mm
7.	Diameter of curtain support pipe	21.6 mm
8.	Length of curtain support pipe	1.274 m
9.	Diameter of bevel gear	26.2 mm
10.	No. of teeth on bevel gear	20
11.	Bore diameter of bearing	20 mm
12.	Diameter of connecting rod	8 mm
13.	Diameter of bearing housing	50.73 mm

Performance evaluation of designed and developed automatic curtain operating system

The particular crop can perform well at optimum temperature and relative humidity. In the greenhouse prototype the change in temperature and relative humidity are recorded at Tansa farm and Research Farm, Dapoli. The dry and wet bulb thermometer was placed in centre of the prototype. The observations of dry and wet bulb temperature were recorded for six days from 7 am to 8 pm daily. The interval of observations was 1 hr. These observations were also taken simultaneously outside the prototype structure in open field. All these observations were taken by keeping the curtains fully open condition and fully closed condition (without automation) to know the maximum and minimum changes in temperature and humidity in Tansa and Dapoli region. The relative humidity was calculated by formula given in equation 3.

$$e_d = 6.112 \times e^{\left(\frac{17.502 \times T_d}{240.97 + T_d}\right)} \quad (1)$$

$$e_w = 6.112 \times e^{\left(\frac{17.502 \times T_w}{240.97 + T_w}\right)} \quad (2)$$

$$\text{Relative Humidity (R. H.)} = \frac{e_w - N(1 + 0.00115 \times T_w) \times (T_d - T_w)}{e_d} \times 100 \quad (3)$$

Where,

e_w = The saturation vapour pressure in the wet bulb temperature, mb

e_d = The saturation vapour pressure in the dry bulb temperature, mb

e = 2.718282

T_d = Dry bulb temperature, °C

T_w = Wet bulb temperature, °C

N = 0.6687452

The automatic curtain rolling system was mounted on the greenhouse prototype and allows to operate automatically. The lower and higher limit values of temperature were set on controller. The observations of temperature and relative humidity inside the greenhouse were recorded from the display unit, and at the same time these observations of outside the greenhouse structure were recorded with the help of digital hygrometer. The position of the side curtains was noted down at every one-hour interval.

Experimental setup of automatic curtain operating system

The Greenhouse prototype of 1.22 m x 0.65 m x 1.22 m was constructed. The Greenhouse prototype structure was fixed with UV stabilized polythene film of 200 micron. At the top curtain and two sides of the greenhouse prototype white shade net having 50 per cent shading effect was fixed. Greenhouse was also provided with arrangement of curtain operating mechanism. At one side of the greenhouse two limit switches were installed, one was installed at 8 cm from the bottom and another was installed at 78 cm height. Inside the greenhouse one AM 2320 sensors for collecting data of temperature and humidity were installed. The developed curtain control system was installed. The view of experimental setup is shown in figure 6.

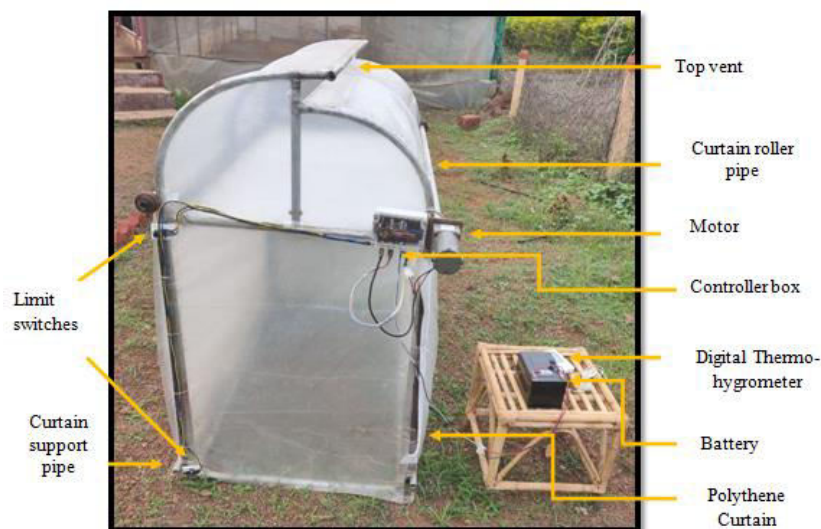


Fig 6: Experimental Setup of Automatic curtain operating system

III. EXPERIMENTAL RESULTS

Automation of the curtain operating system

The controller of automatic curtain operating system was developed by assembling the different components. The hardware connection and connectivity in the form of block diagram is shown in figure 5.

Working of automatic curtain operating system

The lower limit point (28 °C) and higher limit point (32 °C) of temperature was set. The current status of temperature and humidity was displayed on the provided screen.

The current or previous data of temperature and humidity inside the greenhouse was accessed from with the help of website https://agriiot.in/CRS_DAPOLI as shown in Figure 8. The output displays temperature and relative humidity along with date and time. The temperature and relative humidity displayed in degree centigrade and per cent respectively.

The flow chart of working of automatic curtain operating system is shown in Figure 7.

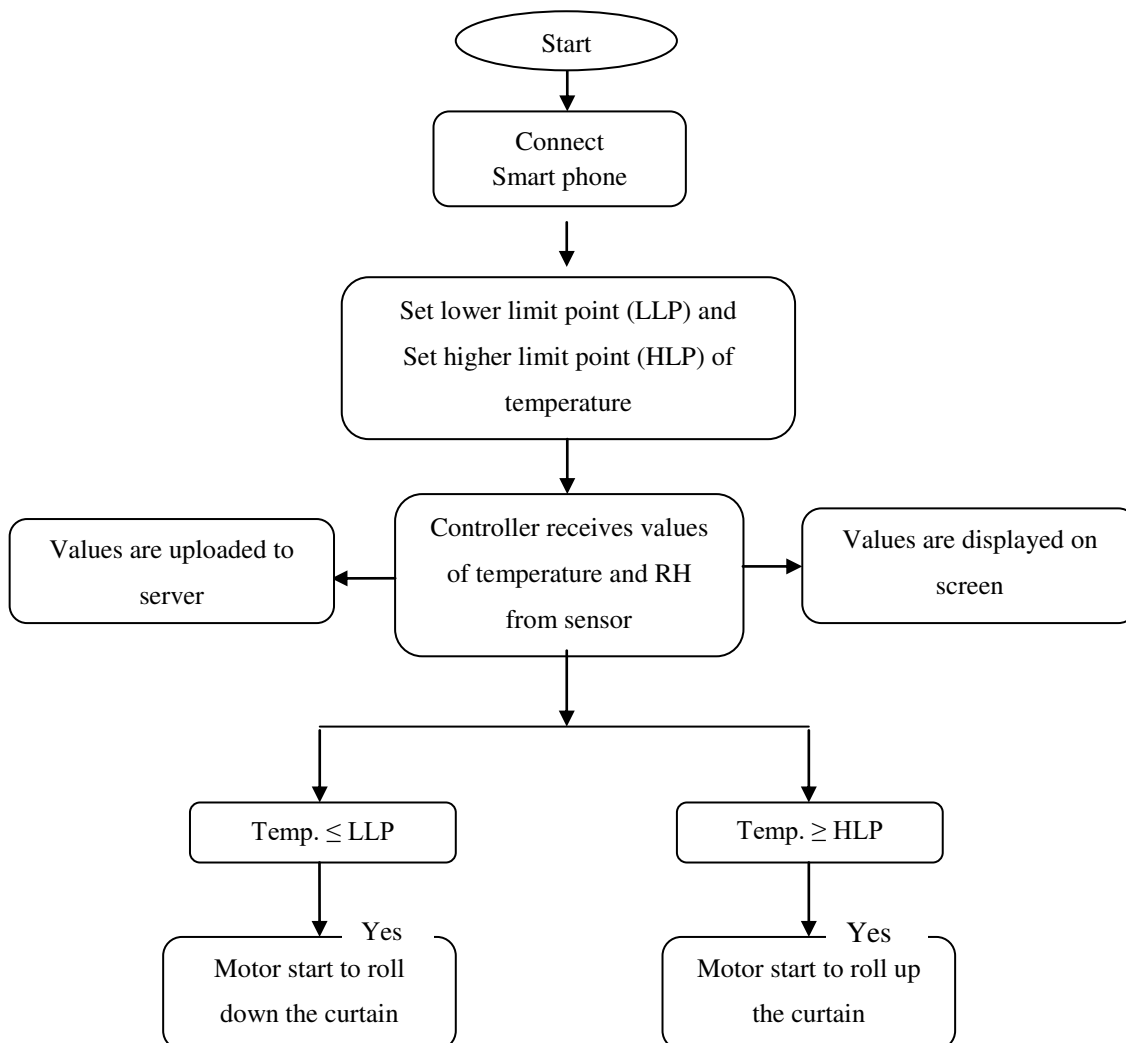
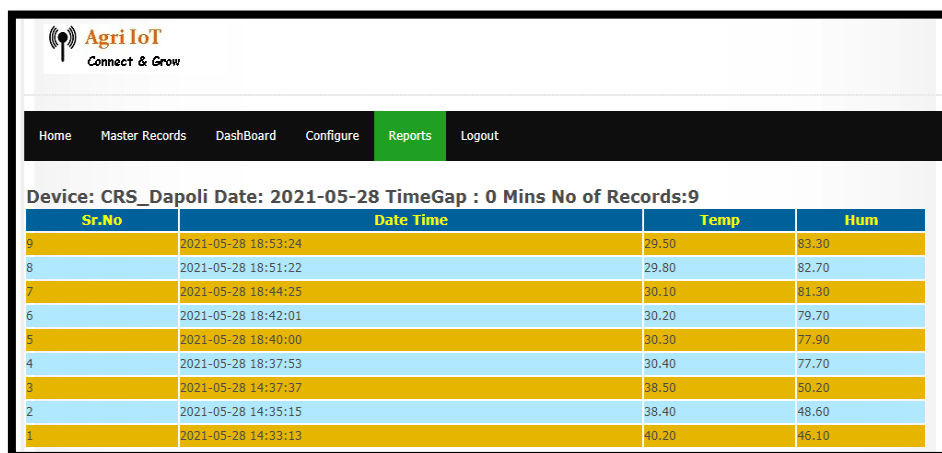


Fig: 7 Flow chart of working of automatic Curtain operating system



Sr.No	Date Time	Temp	Hum
9	2021-05-28 18:53:24	29.50	83.30
8	2021-05-28 18:51:22	29.80	82.70
7	2021-05-28 18:44:25	30.10	81.30
6	2021-05-28 18:42:01	30.20	79.70
5	2021-05-28 18:40:00	30.30	77.90
4	2021-05-28 18:37:53	30.40	77.70
3	2021-05-28 14:37:37	38.50	50.20
2	2021-05-28 14:35:15	38.40	48.60
1	2021-05-28 14:33:13	40.20	46.10

Fig: 8 Screenshots of status of temperature and relative humidity obtained from internet

Performance evaluation of curtain rolling system without automation mechanism

The observations of temperature and inside and outside the greenhouse prototype were recorded Research Farm, Dapoli.

The figure 9 shows the average observations of temperature inside and outside the greenhouse prototype in the month of April. The observations were taken at Research Farm Dapoli. The curtains were in fully closed condition. The figure 9 reveals that the highest and lowest outside temperature was 35.2 °C and 23.7 °C respectively. The highest and lowest inside temperature was 43.4 °C and 25.4 °C respectively. The maximum temperature difference between inside and outside temperature was found to be 8.2 °C in afternoon hours. Whereas the minimum temperature difference between inside and outside temperature was found to be 1.7 °C in morning section. The highest temperature was recorded at 1:00 pm and lowest temperature was recorded at 7:00 am.

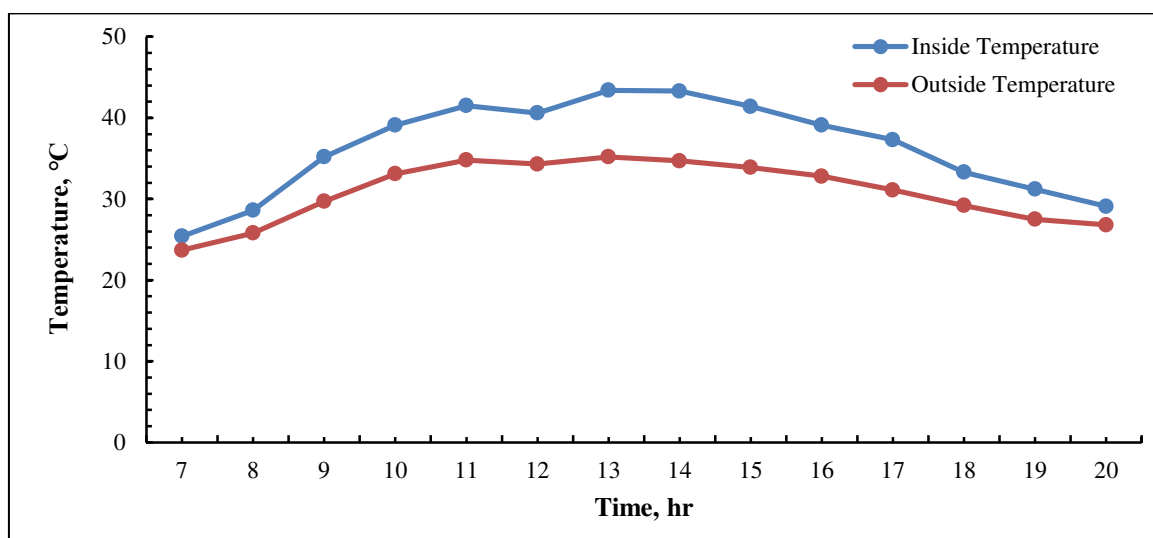


Fig: 9 Inside and outside temperature difference in greenhouse prototype when curtains were closed

The Figure 10 shows the average observations of temperature inside and outside the greenhouse prototype in the month of April. The observations were taken at Research Farm Dapoli. The curtains were in fully opened condition. The Figure 10 reveals that the highest and lowest outside temperature was 36.2 °C and 25.2 °C respectively. The highest and lowest inside temperature was 39.9 °C and 26.4 °C respectively. The maximum temperature difference between inside and outside temperature was found to be 4.1 °C in afternoon hours. Whereas the minimum temperature difference between inside and outside temperature was found to be 0.2 °C in evening hours. The highest temperature was recorded at 1:00 pm and lowest temperature was recorded at 7:00 am.

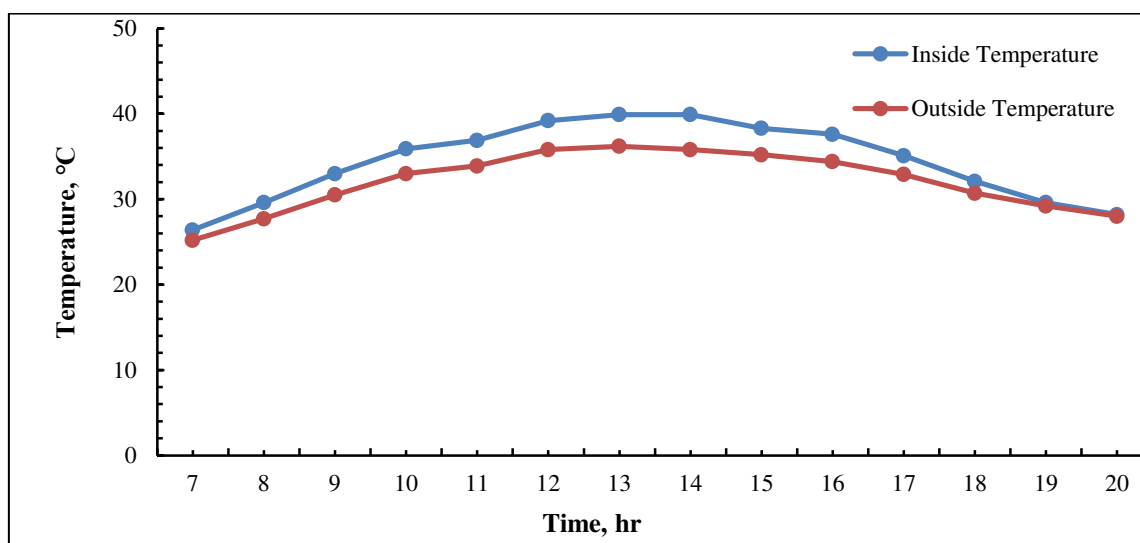


Fig: 10 Inside and outside temperature difference in greenhouse prototype when curtains were opened

The Figure 13 and figure 14 show that the maximum temperature inside the greenhouse prototype was increases up to 8.2 °C when curtains were closed. But when the curtains were opened the maximum raise of temperature inside the greenhouse was 4.1 °C. Thus, it was revealed that to control temperature inside the naturally ventilated greenhouse, rolling and unrolling of curtains was necessary. Similar findings were reported by Ishii *et al.* (2014) [1].

Performance evaluation of automatic curtain operating system

Automation was provided to the curtain operating mechanism on the greenhouse prototype and allows to operate automatically. The observations of temperature and relative humidity inside and outside the greenhouse prototype were recorded. The position of the side curtains was also recorded with respect to time and temperature for three days at Research Farm Dapoli.

Table 3 shows the observations of temperature and relative humidity inside and outside the greenhouse prototype. It also shows the position of curtain with respect to time and temperature. From Table 3 it was observed that when inside temperature of greenhouse prototype goes above the higher limit temperature (32 °C) the curtains were opened. The curtains were opened (roll up) at 8:10 am when outside and inside temperature was 29.80 °C and 32.10 °C respectively. These curtains were remained open until the inside temperature of greenhouse prototype goes below the lower limit temperature (28 °C). It was also observed that the curtains were closed (roll down) at 7:36 pm when outside and inside temperature was 27.90°C and 28 °C respectively.

Table 3 Curtains position with respect to temperature, relative humidity and time

Date: 28/05/2021

Place: Dapoli

Time	Temperature (°C)		Relative Humidity (%)		Curtain Position
	Outside	Inside	Outside	Inside	
7:00 am	27.00	28.90	86	90.00	Close
8:00 am	29.40	31.20	83	86.00	Close
8:10 am	29.80	32.10	80	82.40	Open
9:00 am	30.00	33.40	63	60.00	Open
10:00 am	31.00	34.10	55	53.00	Open
11:00 am	33.40	36.20	51	47.30	Open
12:00 pm	32.90	36.00	54	49.80	Open
1:00 pm	33.70	37.00	57	52.00	Open
2:00 pm	34.90	37.60	55	50.60	Open
3:00 pm	32.00	35.80	60	54.30	Open

Time	Temperature (°C)		Relative Humidity (%)		Curtain Position
	Outside	Inside	Outside	Inside	
4:00 pm	33.20	36.40	58	54.00	Open
5:00 pm	31.00	33.10	67	63.10	Open
6:00 pm	29.80	31.30	71	70.50	Open
7:00 pm	28.80	29.80	81	81.30	Open
7:36 pm	27.90	28.00	83	82.40	Close
8:00 pm	27.20	28.70	85	86.80	Close

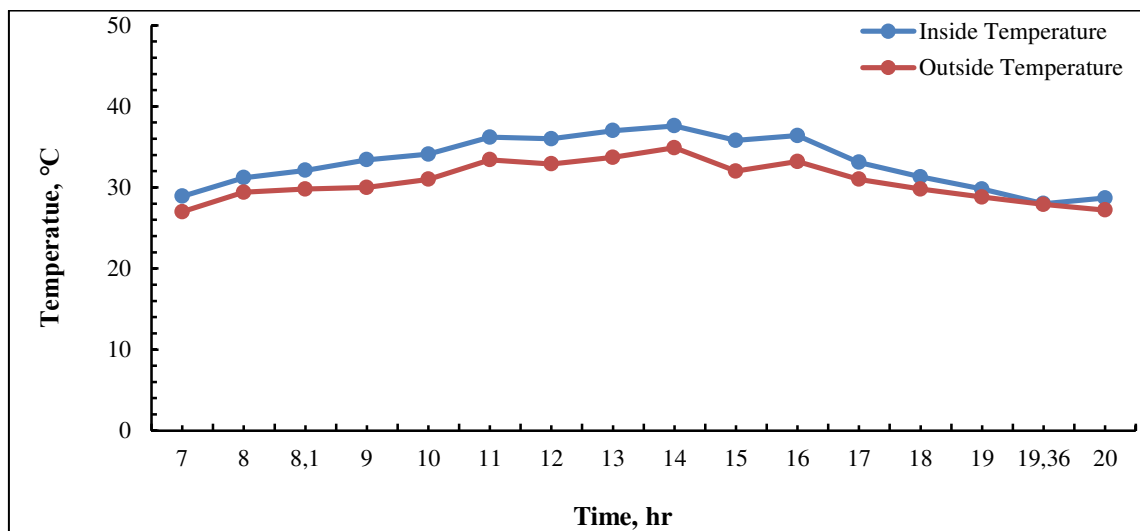


Figure 11 Inside and outside temperature in greenhouse prototype when automatic curtains operation system was installed

The Figure 11 shows inside and outside temperature difference in greenhouse prototype at Research Farm Dapoli. The figure 11 reveals that the highest and lowest outside temperature was 34.90 °C and 27 °C respectively. The highest and lowest inside temperature was 37.60 °C and 28 °C respectively. The maximum temperature difference between inside and outside temperature was found to be 3.9 °C in afternoon hours. The highest temperature was recorded at 2:00 pm. Similar findings were reported by Ishii *et al.* (2014) [1].

IV. CONCLUSIONS

1. The inside temperature of greenhouse structure goes beyond higher optimum limit of crop i.e., 32 °C when side curtains are closed and goes below the lower optimum limit of crop i.e., 28 °C when side curtains are opened.
2. The developed mechanism for rolling up and rolling down of both side curtains simultaneously works satisfactorily.
3. The automatic mechanism for rolling up and rolling down of side curtains works precisely as per the setting of higher and lower limits of temperature.

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