Microclimatic studies in a double-span greenhouse under wind driven and fan ventilated conditions in west coast of India

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Abstract

The microclimate in a double-span greenhouse (with screened vents on all four sides and roof) was studied under wind driven and fan ventilated conditions in 2014-2016. The greenhouse air temperature and relative humidity were monitored year round (ranged from 52.3 to 13.5°C and 100 to 18% in wind driven condition as compared to an ambient air temperature and humidity of 38 to 15°C and 99 to 20%, respectively), while air velocities were measured for short periods with full grown tomato crop at various locations of the greenhouse under wind driven and fan ventilated conditions. The air temperature and relative humidity in the fan (2 nos. 25 cfm)ventilated greenhouse with tomato crop (ranged from 34.4 to 25.3°C and 99 to 30%, respectively, as compared to ambient air temperature and relative humidity of 43 to 11°C, and 96 to 20%, respectively). The highly heterogeneous distribution of air velocities inside the structure under wind driven conditions (east span: (-154.26) to 52.04% and west span: (-68.62) to 39.22%) were improved significantly by the installation of fans (east span: 19.02 to 39.90%, west span: (-57.19) to 39.90%).

Keywords: air velocity, air flow pattern, vent distribution, homogenous microclimate

INTRODUCTION

Greenhouses were introduced in India for commercial cultivation nearly three decades ago and were adopted for commercial cultivation in the 1980s. In spite of the head start, the technology has been adapted to very less extent (40,000 ha) (Singh, 2014) or has faced a lot of problems due to adoption of inadequate designs (Mishra et al., 2010; Singh and Sirohi, 2006; Gupta and Thangam, 2016).

Naturally ventilated greenhouses are cost-effective and have been adopted across the world for crop cultivation (Sanford, 2011). The climate of these structures is strongly influenced by the size and geometry of ventilation windows, size of and configuration of greenhouse, outside conditions (Wind speed, direction, temperatures, humidity) and crop species, growing stage and cultivation methods and hence various studies have been conducted to measure the ventilation rates inside naturally ventilated mono and multi-span greenhouses as affected by ambient wind direction and speed, location and size of vents with and without crop (Boulard, et al., 1997; Kittas et al., 1995, 1996, 1997; Baptista et al., 1999; Dayan et al., 2004; Fernandez and Bailey, 1992; Litago et al., 2005; Papadakis et al., 1996; Jiménez-Hornero et al., 2005; Patil et al., 2008; Teitel, 2007; Teitel and Tanny, 1999; Molina-Aiz et al., 2009; Kittas et al., 2013; López et al., 2014; Stefano et al., 2016).

Naturally ventilated greenhouses have been recommended and introduced across the Indian sub-continent for successful crop cultivation (Ganguly and Ghosh, 2009; Kumar et al., 2009) but location specific modification of these structures would lead to more profitable crop cultivation (Chandra et al., 2002).

The present study was conducted in the state of Goa (15°17’57” Lat, 74°7’26” Long) which is located in the western coast of India, characterized by high rainfall (3183 mm $annum^{-1}$), moderate to high temperature (33.3 to 22.5°C) and high humidity (59.2 to 87.8%) conditions. It has a high influx of international and domestic tourists throughout the year. To

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overcome the shortfall of vegetables and flowers demand, the state Government has sanctioned around 120 units of naturally ventilated greenhouses (area ranging from 500 to 2000 m^2) for vegetables and flowers production. These naturally ventilated greenhouse designs, popular and performing well in neighboring states of Karnataka and Maharashtra have failed to deliver the microclimate suitable for vegetable production under west coast climatic conditions. Hence, research on the existing designs, their microclimate, and possible modifications to make the existing designs suitable for profitable crop production for this ecosystem was carried out at ICAR-Central Coastal Agricultural Research Institute, Goa.

MATERIALS AND METHODS

The experimental greenhouse

A double-span greenhouse, located in ICAR-CCARI (15°29'15" Lat., 73°55'20" Long) was 24 m long and 20 m wide (480 m^2 ground area), having a ridge height of 6.5 m and gutter height of 4.0 m, with gutters oriented 12° north east-south west, divided into two spans each 10 m width. It had 5 m curved vents (120 m^2 each along length and 100 m^2 on ends with 50% shade net (20 Mesh) fitted on them on all four sides at 1.0 m from ground level and to the gutter and also 0.5 m wide vents along the ridge in both spans (Figure 1).

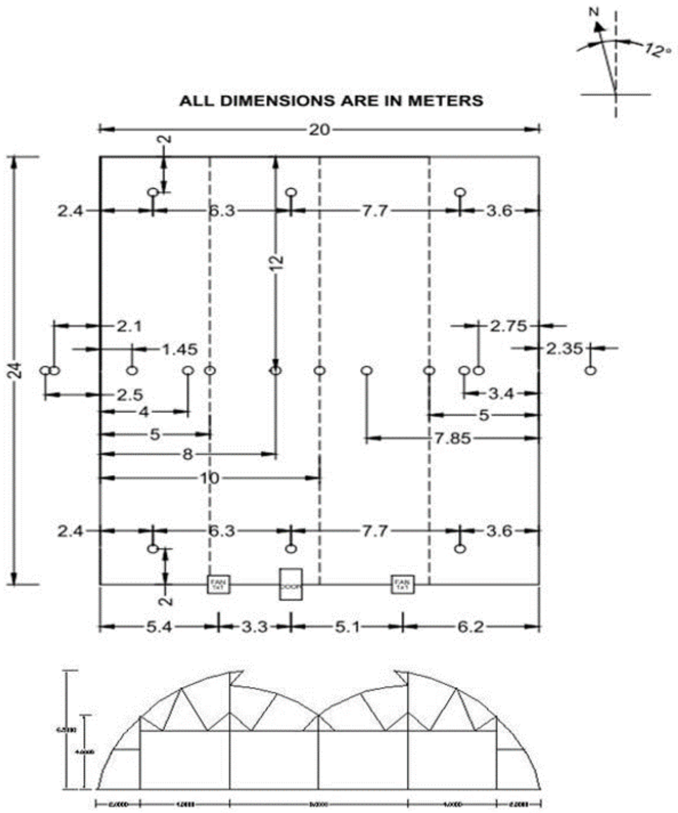

Figure 1. Layout of sensors in greenhouse.

The experiments were carried out in this greenhouse from 2014 to 2015 in wind driven condition with tomato crop with all vents 75% open and 2015-16 in ventilated condition with horizontal axial flow mixer fans (4 nos. one for each compartment -48" slow belt driven 1.5 Hp, 3 Phase, capacity 2943 cfm) and ventilating fans (2 nos, one for each span, 1 m dia and 24500 cfm capacity) introduced (Table 1 summarizes the dates and details of the experiments).

Table 1. Dates and details of the experiments.

S.no.	Details of experiments	Dates	Crop in the greenhouse
1	Ventilation and microclimate studies under wind driven condition	2 January 2015 to 21 February, 2015	Tomato crop[a]
2	Ventilation and microclimate studies under fan ventilated conditions	27 January 2016 to 16 March, 2016	Tomato crop[b]

Temperature humidity and dew point temperatures were monitored throughout the crop period (a - October, 2014 to March 2015, b - September 2015-March 2016) at 6 or more locations and averaged.

All experiments were carried out with the two top vents fully open (12 m^2 each) and side vents three quarters open (0.75% of 120 = 90 m^2 each along length and 75 m^2 on ends). Temperature and humidity were recorded at various locations (6 or more) in the greenhouse using temperature humidity dataloggers (EL-USB- 2 LCD type, Lascar Electronics, Essex, UK, accuracy ± 0,5°C, resolution 0.5°C, range -35 to 80°C and humidity, accuracy ±3%, resolution 0.5% RH, 0-100% RH range).

Air flow speed and direction were measured using 3 Windsonic 2D sonic anemometers (Gill Instrument LTD, Lymington, Hampshire, UK; resolution: 0.01 m s^{-1}; accuracy 2%), placed at 1.3 m at various positions (Figure 1) inside and outside (near west and east side vents) the greenhouse to get velocity profile as influenced by ambient. The data was with a tomato crop planted in double rows in soil based beds in the whole greenhouse, October 2014-March 2015 in wind driven conditions and September 2015-March 2016.

The data for temperature, humidity and dew point temperature was taken at least 6 or more locations, averaged and S.D. was calculated (the sensors were protected from direct sunlight). The data for temperature and humidity was recorded every hour throughout the crop period, whereas air flow experiments were conducted in a particular layout for 3 continuous days and data recorded every 5s and averaged over every hour.

RESULTS AND DISCUSSION

Ventilation (2 January 2015 to 21 February 2015) and its effect on crop microclimate (October 2014 to March 2015) under wind driven conditions with a tomato crop

The air velocities, temperature and humidity were recorded at various locations inside the greenhouse with a full grown tomato and compared with ambient wind velocities, temperature and humidity. The results are summarized in Figure 2.

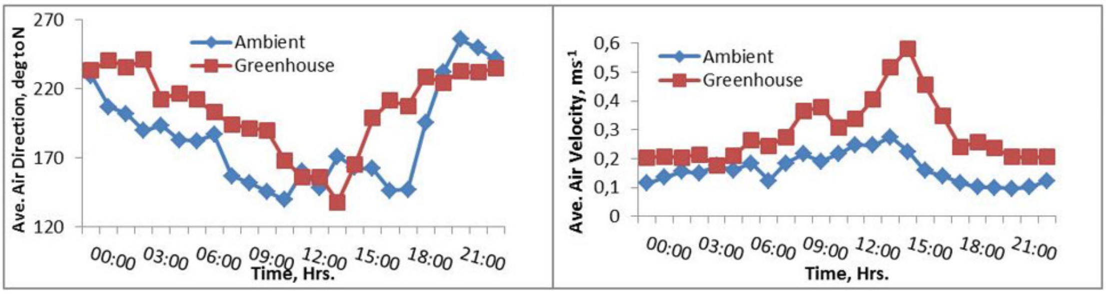

Figure 2. Diurnal course of air velocity and direction inside and outside wind driven greenhouse.

A clear relationship could not be established between air directions in the greenhouse and the direction of the ambient wind, this could be because the tomato rows were along the length of the greenhouse and thus the air was more from the end of the greenhouse parallel to the rows. The air velocities in the greenhouse had a positive correlation with the ambient air velocity with an R^2 of 0.49 (Figure 3). But the distribution of air velocity in the greenhouse were found to be very heterogenous i.e. east span: (-154.26) to 52.04% and West span:

(-68.62) to 39.22%) with respect to center.

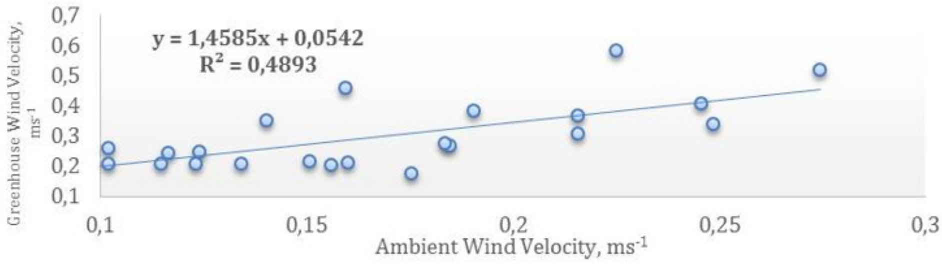

Figure 3. Relationship between ambient wind and greenhouse air velocity in wind driven greenhouse.

The variation of wind velocities and direction at three heights viz., 1.3, 2.5 and 4.5 m in the center of the greenhouse wih the tomato crop was studied and the results are summarized in Figure 4. The results show that during day time, the air velocity was maximum at 2.5 m followed by 1.3 m and was the minimum at 4.5 m height, showing that movement of air was mostly influenced by the side vent and less by the roof vent. This result agrees with that of Boulard and Draoui (1995), which states that at wind speeds less than 2 m s^{-1}, both stack and wind had same effect.

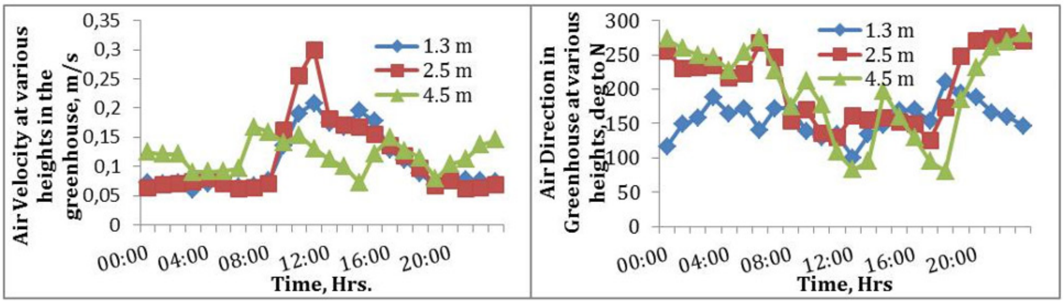

Figure 4. Effect of height on air pattern in the wind driven greenhouse with tomato crop.

Table 2 summarizes the temperature and humidity in the greenhouse and ambient during the whole crop period. The average temperature and humidity in the double span greenhouse during the warmer months of January-March were higher than the ambient showing the inadequacy of the wind driven condition greenhouse to maintain favorable microclimate. The hourly greenhouse air temperature and relative humidity ranged from 52.3 to 13.5°C and 100 to 18% in wind driven condition as compared to an ambient air temperature and humidity of 38 to 15°C and 99 to 20%, respectively.

Ventilation (27 January 2016 to 16 March 2016) and microclimate studies (September 2015 to March 2016) under fan ventilated conditions with a tomato crop

Results of studies on microclimate vis-à-vis temperature and humidity (throughout crop period), air velocity and direction (fan operation period between 8 am to 4 pm between 27 January 2016 to 16 March 2016) in the fan ventilated greenhouse as compared to the ambient have been summarized in Figure 5 and Table 3.

Table 2. Average conditions in the naturally ventilated greenhouse with tomato crop (October 2014 to March 2015).

S.no.	Month	Ave. temp ± S.D. (°C)		Ave. rel. hum. ± S.D. (%)	
		DSGH	Ambient	DSGH	Ambient
Day (8-17 h)					
1.	October	34.31±4.65	34.80±5.08	63.90±15.58	65.35±15.95
3.	November	34.78±4.21	35.95±6.38	54.49±13.93	53.14±17.76
4.	December	33.30±4.53	33.05±7.12	55.43±15.18	54.53±19.31
5.	January	32.02±5.09	30.85±10.17	53.61±16.50	57.73±28.09
6.	February	34.40±5.21	29.25±6.50	50.08±17.15	61.78±19.73
7.	March	35.58±4.27	34.47±1.62	57.51±14.20	50.43±9.76
Night (18-7 h)					
2.	October	25.11±2.03	23.54±1.63	92.21±5.58	92.24±5.28
3.	November	23.72±2.44	20.82±2.60	88.88±7.18	89.35±6.88
4.	December	22.67±2.61	20.76±2.83	85.37±8.90	82.14±11.71
5.	January	21.03±3.15	20.31±2.78	83.53±10.24	77.47±20.00
6	February	22.49±3.22	22.72±2.46	83.07±11.02	74.52±12.33
7	March	25.48±3.03	22.79±2.36	84.38±9.01	90.32±5.25

Average value ± standard deviation.

Table 3. Average conditions in the fan ventilated greenhouse with tomato crop (September 2015 to March 2016).

S.no.	Month	Ave. temp. ± S.D. (°C)		Ave. rel. hum. ± S.D. (%)	
		DSGH	Ambient	DSGH	Ambient
Day (8-17 h)					
1	September	31.27±3.59	30.85±3.48	79.58±11.24	78.73±9.79
2	October	32.38±3.94	33.13±4.41	72.98±13.75	68.48±14.50
3	November	32.11±4.19	34.71±4.13	61.22±13.23	50.96±10.61
4	December	30.94±4.43	33.20±3.92	61.29±14.82	51.09±12.40
5	January	30.17±4.71	34.19±4.50	60.66±14.66	45.42±10.61
6	February	32.06±4.57	35.40±3.43	63.22±16.22	49.58±12.56
7	March	33.87±4.00	35.05±2.90	61.03±13.69	52.35±11.48
Night (18-7 h)					
1	September	24.89±1.18	24.37±1.18	95.15±3.59	93.33±3.54
2	October	24.33±1.58	23.54±1.63	94.30±4.25	90.43±8.30
3	November	21.95±2.64	20.82±2.60	89.37±6.06	76.65±8.25
4	December	21.89±2.96	20.76±2.83	86.94±7.62	76.84±8.25
5	January	21.48±3.02	20.31±2.78	84.93±8.23	79.59±7.98
6	February	24.06±2.71	22.72±2.46	87.31±8.19	79.92±7.03
7	March	24.37±3.19	24.14±3.26	85.92±8.94	80.13±8.42

Average value ± standard deviation.

Here there was a clear correlation between the ambient wind and greenhouse air direction when the ambient wind direction was almost parallel to the greenhouse length, a correlation coefficient (R^2) of almost 0.55 was found for these values. The air velocities in the greenhouse had significant relationship with ambient wind velocity (Figure 6) with an R^2 of almost 0.7, but this correlation seemed to reduce the effect of fan which resulted in lower average air velocities as compared to the ambient wind velocity. But the fan ventilation reduced the heterogeneity in the velocities (east span: 19.02 to 39.90%, west span: -57.19 to 39.90%). Further studies on the direction of ambient wind, sensor based vents and fan operations and its effect on crop microclimate are required.

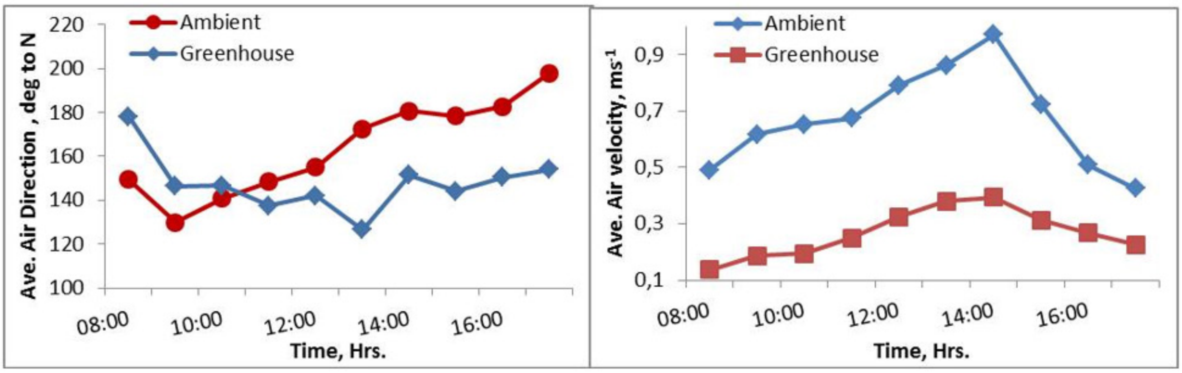

Figure 5. Diurnal course of air velocity and direction inside and outside fan ventilated greenhouse.

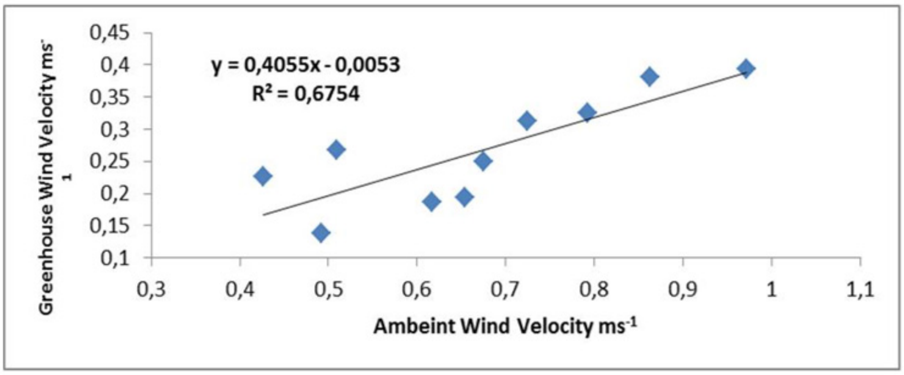

Figure 6. Relationship between ambient wind and greenhouse air velocity in fan ventilated greenhouse.

Overall average air velocities in the fan ventilated greenhouse were lower than that in wind driven greenhouse but this was due to only penetration of the wind close to the vents. A comparison of the air velocities in the center for wind driven and fan ventilated is given in Figure 7, it is clearly visible that the air velocities in both conditions were similar. But average microclimate conditions during whole crop period under fan ventilated conditions (Table 3) clearly indicate a better microclimate existed in the fan ventilated greenhouse. A higher capacity of ventilation fans could further improve the ventilation rates. The temperature and humidity during the tomato growth period in the fan ventilated greenhouse ranged from 34.4 to 25.3°C and 98.6 to 30.1% respectively, while the ambient temperature and humidity ranged from 43 to 11°C and 96 to 20% respectively. The fan ventilated greenhouse could successfully reduce the extreme ambient conditions and the crop. But the ventilation rates of fans need to be increased to obtain better ventilation rates and sensor based opening of vents and fan operation to synergise the ambient wind needs to be studied.

CONCLUSIONS

Studies under wind driven and fan ventilated conditions in a double span greenhouse with roof and side vents under west coastal ecosystem of India has proved that natural ventilation is inadequate to maintain homogenous microclimate in the greenhouse. The greenhouse air temperature and relative humidity in wind driven condition ranged from 52.3 to 13.5°C and 100 to 18% as compared to an ambient air temperature and humidity of 38 to 15°C and 99 to 20%, respectively. Fan ventilation has improved the microclimate in the greenhouse, but air flow through the vents has reduced the fan induced air velocities in the greenhouse. The temperature and humidity during the tomato growth period in the fan ventilated greenhouse ranged from 34.4 to 25.3°C and 98.6 to 30.1%, respectively, while the ambient temperature and humidity ranged from 43 to 11°C and 96 to 20%, respectively. Hence since a clear cut effect on ventilation rates ould not be seen due to introduction of the two fans, further studies on capacity of fans, closing and opening of vents, dynamic operation of fans as influenced by external wind direction and speed should be studied and developed to reduce ventilation costs and also improve the crop microclimate under the west coastal ecosystem of India.

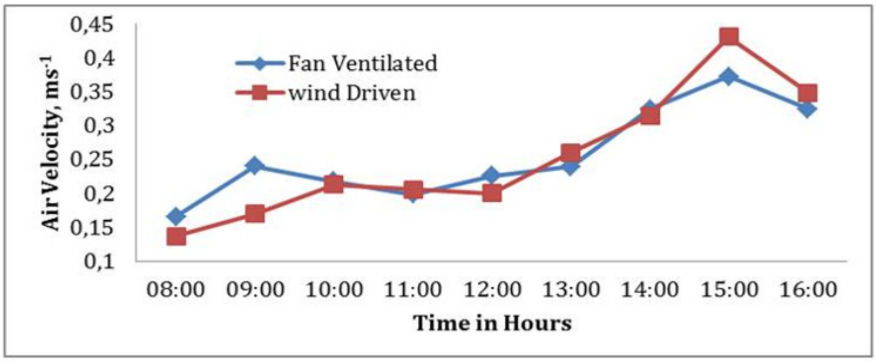

Figure 7. Diurnal course of air velocity and direction inside and outside fan ventilated greenhouse.

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