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Effect of anti-aphids and anti-bemisia insect proof screens on the inside microclimate in a naturally ventilated bi span greenhouse: a cfd study

V.Bharath[1], M.V.Puneeth Kumar[2]

[1,2]Department of Mechanical Engineering, SVCE, Karnataka, Bengaluru, India

Email ID - vbharath1947@gmail.com, puni053@gmail.com

Abstract: **An analysis of the distributed climate in a bi-span tunnel type greenhouse equipped with fine mesh insect proof screens and crop inside is numerically investigated. The present study involves natural ventilation and convective mode of heat transfer in a particular greenhouse design. The results for the air flow and temperature distributions are presented for various external wind speed and temperatures in both 2D and 3D .The complete modeling and mesh generation is obtained using Gambit and analyzed using Ansys Fluent CFD code. The present study is expected to be useful for greenhouse manufacturers to improve greenhouse designs and the horticulturists for better understanding the greenhouse climate and its control.**

Keywords: **Greenhouse, Climate, CFD**

I. Introduction

The crop production under protected environment is increasing steadily. The design and ventilation system performance are the most important factors responsible for climatic control and yield quality of protected cultivation. The exchange of air between inside and outside in order to dissipate excess heat, maintain humidity and increase the exchange of carbon dioxide and oxygen is influenced by the ventilation of greenhouse. Ventilation provides cooling and removes humidity based on inside conditions during summer whereas it removes excess humidity during winter. The ventilation may be natural or forced. The pressure differences caused by the wind effect or temperature effect or both are responsible for natural ventilation. Forced ventilation is caused by the use of fans. The natural ventilation type is most widely used as it consumes less energy, requires less equipment maintenance and is much cheaper than other systems for controlling greenhouse climate. The airflow patterns oversee the temperature, humidity as convective heat and mass transfers dictate the exchange process in ventilated structure [1]. Hence there is a need to understand these air flow patterns in order to control climate inside greenhouses and to improve naturally ventilated greenhouse designs. The utilization of Computational Fluid Dynamics (CFD) to analyze the greenhouse climate distribution is growing with the advent of better computers. Some studies are carried out employing either two dimensional (2D) or three dimensional (3D) CFD models taking into account influence of insect screen,wind direction [2], wind speed, direction, and vent opening size [3] effects on the climate inside the greenhouses. However the results achieved could not be generalized [4] due to different designs and conditions. The CFD has also been employed to redesign the shape of the greenhouse roof [5] in order to reduce the overall temperature level to help increasing natural flow rate for improving the crop productivity.

Thepresent study utilizes both 2D and 3D CFD models to analyze the airflow and temperature distributions inside a particular greenhouse design consisting of two spans by considering different external velocities of air at the inlet, temperatures and two types of insect-proof screens, utilizing ANSYS FLUENT software package. The mesh is generated using GAMBIT v.2.3.1 module and the problem is solved using FLUENT v.6.3.26 module which is based on finite volume method.-

II. Mathematical Formulation

Physical Model and the Coordinate System

A Cartesian coordinate system is opted to describe the geometry. The origin is placed at the middle of the greenhouse floor with the positive direction along the x-axis, the negative direction away from the x-axis and the positive direction of the y-axis is considered vertically upwards.i and j are the unit vectors along x- and y- directions. . For generality, the gravity vector$\vec{g}$inFig. 1 is shown to make angles θ_x and $\theta_y$with x- and y- directions respectively, a non inclined domain for both 2D and 3D is considered in the present work with $\theta_x = 90º$, $\theta_y = 180º$ and $\theta_z = 90º$.The z-direction comes into picture only when 3D model is considered, with the positive direction towards the front and the negative direction towards the rear axially as shown in Fig. 2.

In Fig. 1, ABCDKIHGEA represents the outside environment of the greenhouse (extended computational domain), EGHIKE represents the inside environment of the greenhouse (computational domain). The air flow inlet on the left side AB of the domain is of height H and the outlet

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is also of the same height on the right side CD. The height of the ridge is $H_1 + H_2 + H_3$ and that of the eaves EG and KI is $H_1 + H_2$ .GF and IJ are the side ventilators of the greenhouse with opening height H_2 and the side walls EF, KJ are of height H_1. The soil outside the greenhouse is given by AE, KD with total width $W_1 + W_4$ and the inside soil represented by EK is of width $W_2 + W_3$. The width and height of the crop is $W_2 + W_3$ and H_1 . The overall width and height of the whole domain in 2D are W and H respectively. In 3D, the total axial length of the total domain is L. Therefore volume of the total domain in 3D is W*H*L.

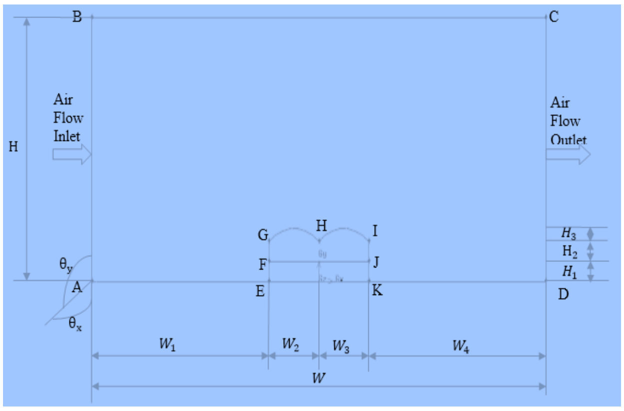

Fig. 1 The Physical Model and Coordinate System in 2D

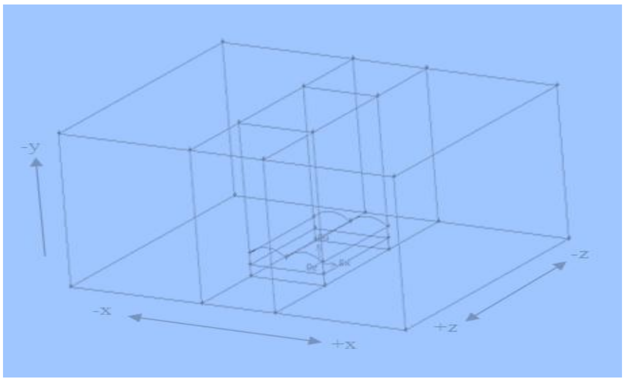

Fig. 2 The Physical Model and Coordinate System in 3D

Governing Equations

The partial differential equations expressing the conservation of mass, momentum, energy, turbulence kinetic energy and turbulence kinetic energy dissipation rate represent the governing equation for the present problem.

Continuity equation

$$\vec{\nabla}.\vec{u}=0 \qquad (1)$$

Momentum equation

$$(\vec{u}.\vec{\nabla})\vec{u} = -\frac{1}{\rho}\vec{\nabla}p + [(\gamma+\gamma_t)(\overrightarrow{\nabla}^2.\vec{u})] - \beta(T-T_r)\vec{g}.\frac{\vec{u}}{|\overrightarrow{u}|} - \frac{1}{\rho}\left[\frac{\mu}{\alpha}\vec{u} + \frac{C_2}{2}\rho\vec{u}.\vec{u}\right] \qquad (2)$$

The fourth term in the RHS is included only in the regions of the crop and insect screens which are considered as porous media.

Energy equation

$$E(\vec{\nabla}.\vec{u}) = -\frac{P}{\rho_f}[\vec{\nabla}.\vec{u}] + \frac{1}{\rho_f}\vec{\nabla}[k_{eff}(\vec{\nabla}.T)] \qquad (2)$$

The complete set of equations of the $K-\varepsilon$ is found in [6] and their commonly used set of parameters are $C_\mu = 0.09, C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92, \sigma_k = 1, \sigma_\varepsilon = 1.3$[7].

Boundary Conditions

The starting conditions for the iterative solutions are quiescent state and a uniform temperature throughout the domain. The fluid enters at the inlet AB with a known velocity and exits at the outlet CD as a fully developed flow. A no slip and no permeabilty hydrodynamic conditions is prescribed at the top and bottom surfaces AD and BC of the total domain. The fluid enters the domain at the specific temperature and is assumed to leave at the outlet with no temperature gradient. The temperature of the soil inside and outside the greenhouse EK,AE and KD are constant and the side walls EF and KJ have zero heat flux. A pressure gradient is specified along screens GF and IJ.

NUMERICAL FORMULATION

III. Solution Procedure

The present problem is solved using ANSYS FLUENT software package. The mesh is generated using GAMBIT v.2.3.16 module which is imported into FLUENT v.6.3.26 module and the results are obtained by global iterative process with the choice of implicit steady state equations and pressure based solver. The Semi Implicit Method for Pressure Linked Equations (SIMPLE) algorithm is applied for pressure-velocity coupling. The Boussinesq model is activated to account for the effects of buoyancy force due to air density differences on the greenhouse ventilation. The high air flow rates and heat transfer interactions in the flow field cause turbulent motion of air [8]. Hence a standard $\mathbf{K-\varepsilon}$ model assuming isotropic turbulence in the core with standard wall functions near the walls is adopted. The

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porous medium approach is utilized to consider the effects of insect-proof screens [9] and the input values for screen are found in [10]. The crop is simulated as porous obstacles with inertial and viscous resistance [11]. A second order upwind discretization scheme is used for momentum, turbulence equations to obtain better accuracy. For pressure PRESTO discretization scheme is chosen since it yields good results in the presence of the porous medium and the Power law is used for energy equations to obtain favorable convergence.Tables 1,2,3 shows the basic components, greenhouse dimensions and boundary values used in simulations.

TABLE 1 THE BASIC COMPONENTS OF CFD MODEL

	Setting
Solver	**2D, 3D**
	Implicit formulation
	Absolute velocity formulation
	Steady state analysis
Energy	**Activated**
Viscous	**Standard K-ε model** **Standard wall function**

Table 2 Greenhouse Dimensions

Parameters	Dimensions (m)
Greenhouse length	**15**
Greenhouse width	**11**
Side height	**3**
Ridge height	**4**
Vent opening	**1.5**
Crop height	**1.5**

TABLE 3 BOUNDARY VALUES USED IN SIMULATIONS

Parameters	Input values
Winddirection	**Perpendicularto**
Inlet Velocity	**3m/s** **4m/s**
Outside Airtemperature	**298K**
Outside Soil temperature	**303K**
Inside Soil temperature	**308K**
Roof filmtemperature	**318K**
Turbulenceintensity	**2%**
Turbulencescale	**0.04**
Inertial Resistance	**1.534(1/m)**
Viscous Resistance	**27380(1/m2)**

Grid Sensitivity

Grid independency tests are carried out for both 2D and 3D models. For 2D model tests are carried out considering convective heat transfer mode for five meshes containing quadrilateral cells numbering 16320, 21112, 25600, 31302 and 35400 where as for 3D model meshes containing hexahedron cells numbering 1076860, 1169413, 1287195, 1420876 and 156565 are employed. Since there is no appreciable change in results the mesh of 25600 quadrilateral elements and 1420876 hexahedron elements are opted for 2D and 3D computations respectively.

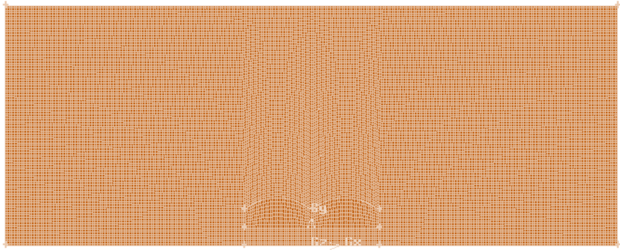

Fig. 3 Typical 2D Model Mesh with 25600 cells

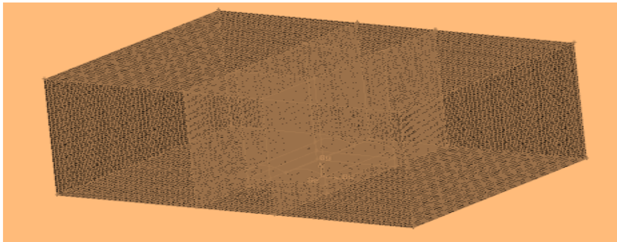

Fig. 1 Typical 3D model mesh with 1420876 cell

V. Results and Discussions

Flow Field

In the examined field, two recirculation patterns are observed. A large recirculation pattern is observed in the span S_1 formed due to the curved shape of the roof and absence of roof opening, and a small recirculation just below the roof of the span $S_2$is seen because of the presence of the plants. The average air velocities inside the canopy is lower and vary between 1/25 to 1/40m/s depending on the parametric inlet velocity range chosen since the viscous and inertial resistances decelerate flow velocities inside the porous region. A reversed flow inside the canopy in the span S_1 is seen and profile is shown in Fig.4. A similar observation but restricted to the centre of the greenhouse is made by [9]. Fig. 5 and 6 represents the horizontal air velocity along the greenhouse length and 2D streamline plot of resultant velocity respectively.

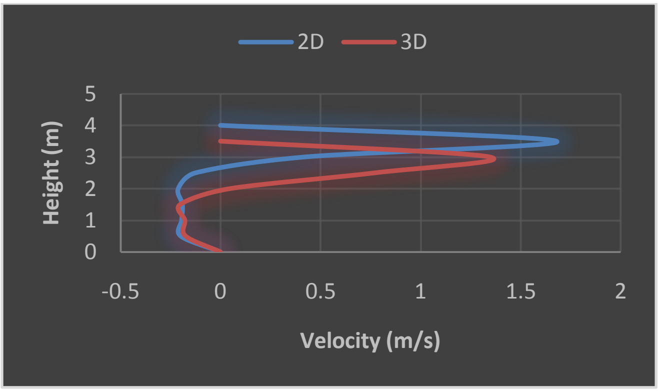

Fig. 2 Modeled Profile of the Horizontal Wind Speed in the Centre of the Span1

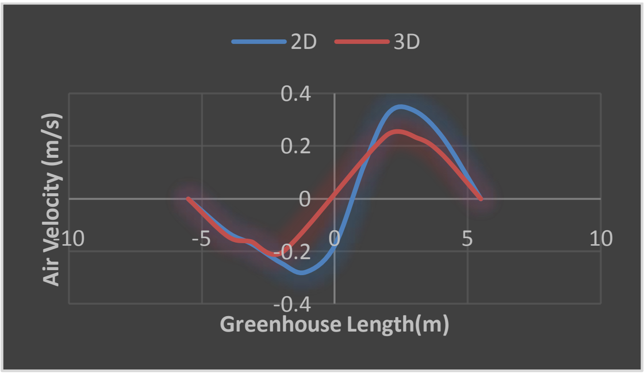

Fig. 3 Horizontal Air Velocity Distribution along the Greenhouse Length

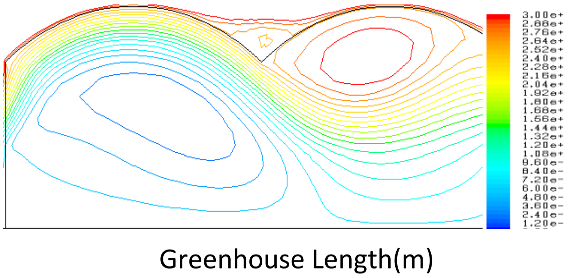

Fig. 62D Streamline Plot of Resultant Velocity Inside Greenhouse with Inlet Ielocity 5m/s for Anti-Aphids Screen

Temperature Distributions

Convection is the main heat transfer mechanism. The temperature of the entering stream prevails over the whole domain, except in the region where there is recirculation and reduced air velocity. The temperature is affected by the warmer roof and ground shown in Fig. 6. From Fig. 7 it is apparent that the high temperatures are confined to the immediate neighborhood of the solid surafces intercepting with the fluid and Fig. 8 shows the 2D contour plot of static temperature inside greenhouse.

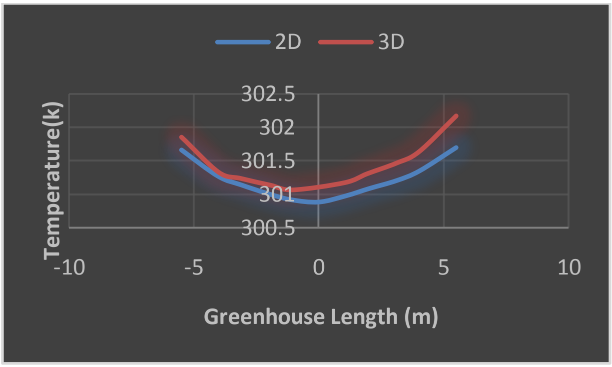

Fig. 4 Air Temperature Distribution along the Greenhouse Length

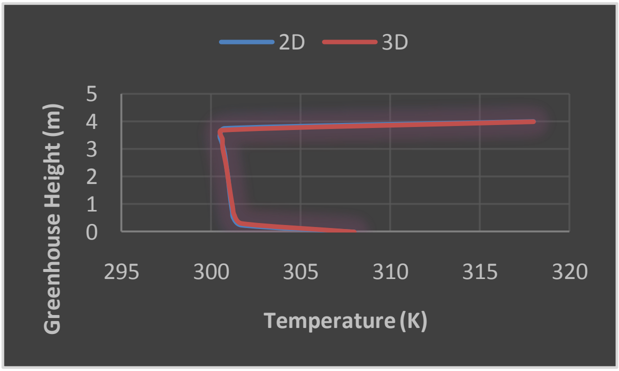

Fig. 5 Modeled Vertical Profile of Air Temperature in the Middle of Span 1

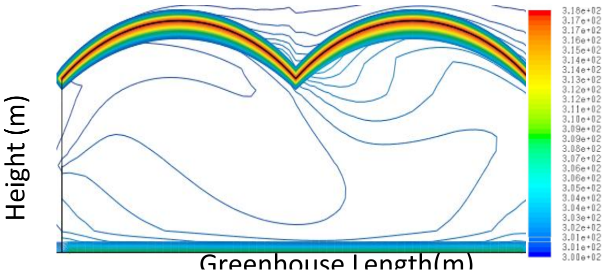

Fig. 6 2D Contour Plot of Static Temperature Inside Greenhouse with Inlet Velocity 5m/s for Anti-Aphids Screen

Figs 4, 5, 7, 8 are plotted for inlet velocity of 5m/s and anti-aphids screen. They demonstrate that the profiles and distributions obtained for 2D and 3D are analogous. The results of parametric studies for various inlet velocities and the influence of the type of insect screen on temperature arefor both 2D and 3D are shown in Tables 4 and 5 respectively.

TABLE 4 INFLUENCE OF THE INLET VELOCITY ON MEAN INSIDE AIR TEMPERATURES WITHIN CANOPY AND TOTAL GREENHOUSE WITH ANTI-APHIDS AND ANTI-BEMISIA SCREEN FOR EXTERNAL TEMPERATURE 298 K AND 300 K (*ITALICS*) [2D MODEL]

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Inlet velocity (m/s)	Anti-Aphids screen		Anit-Bemisia screen	
	T_{canopy}(K)	T_{total}(K)	T_{canopy}(K)	T_{total}(K)
3	*300.05* *(301.67)*	299.97 *(301.59)*	300.14 *(301.74)*	299.98 *(301.69)*
4	299.74 *(301.41)*	299.68 *(301.38)*	299.80 *(301.46)*	299.74 *(301.43)*
5	299.55 *(301.25)*	299.51 *(301.24)*	299.61 *(301.30)*	299.56 *(301.28)*

TABLE 5 INFLUENCE OF THE INLET VELOCITY ON MEAN INSIDE AIR TEMPERATURES WITHIN CANOPY AND TOTAL GREENHOUSE WITH ANTI-APHIDS AND ANTI-BEMISIA SCREEN FOR EXTERNAL TEMPERATURE 298 K AND 300 K (*ITALICS*) [3D MODEL]

Inlet velocity (m/s)	Anti-Aphids screen		Anit-Bemisia screen	
	T_{canopy}(K)	T_{total}(K)	T_{canopy}(K)	T_{total}(K)
3	299.88 *(301.57)*	299.92 *(301.64)*	299.97 *(301.65)*	300.02 *(301.71)*
4	299.57 *(301.08)*	299.62 *(301.38)*	299.73 *(301.36)*	299.69 *(301.44)*
5	299.37 *(301.13)*	299.44 *(301.22)*	299.43 *(301.18)*	299.49 *(301.26)*

Ventilation Rate

The ventilation rate is found to increase with the external wind speed and the values for both the anti-aphids and anti-bemisia insect proof screens are summarized in Table 6 and 7 for 2D and 3D respectively.

TABLE 6 INFLUENCE OF THE INLET VELOCITY ON AIR FLOW RATE AND AIR RENEWALS WITH ANTI-APHIDS AND ANTI-BEMISIA SCREEN FOR EXTERNAL TEMPERATURE 298 K AND 300 K (*ITALICS*) [2D MODEL]

Inlet velocity (m/s)	Anti-Aphids screen		Anit-Bemisia screen	
	Air flow rate (m^3/s)	Air renewals [h^{-1}]	Air flow rate (m^3/s)	Air renewals [h^{-1}]
3	0.80 *(0.79)*	71.08 *(70.18)*	0.75 *(0.74)*	66.64 *(65.75)*
4	1.28 *(1.27)*	113.73 *(112.84)*	1.22 *(1.20)*	108.40 *(106.62)*
5	1.82 *(1.81)*	161.70 *(160.83)*	1.74 *(1.73)*	154.61 *(153.72)*

TABLE 7 INFLUENCE OF THE INLET VELOCITY ON AIR FLOW RATE AND AIR RENEWALS WITH ANTI-APHIDS AND ANTI-BEMISIA SCREEN FOR EXTERNAL TEMPERATURE 298 K AND 300 K (*ITALICS*) [3D MODEL]

Inlet velocity (m/s)	Anti-Aphids screen		Anit-Bemisia screen	
	Air flow rate (m^3/s)	Air renewals [h^{-1}]	Air flow rate (m^3/s)	Air renewals [h^{-1}]
3	10.32 *(10.24)*	61.06 *(60.59)*	9.71 *(9.71)*	57.45 *(57.45)*
4	17.06 *(16.93)*	100.94 *(100.17)*	16.13 *(16.12)*	95.44 *(95.38)*
5	24.79 (24.62)	146.68 *(145.67)*	23.55 *(23.52)*	139.34 *(139.17)*

Conclusions

CFD calculations are performed in order to obtain information on flow and temperature distributions regarding the greenhouse climate.

- The external temperature and inlet velocity play important roles on the inside greenhouse climate.
- The plants and screens have crucial role on the air flow pattern and temperature inside greenhouse.
- The ventilation rate increases with the increase in inlet velocity. It is found that when the inlet velocity is 5 m/s the ventilation rate is about 1.45 times higher than 4 m/s and 2.4 times than 3 m/s for anti-aphids screen.

NOMENCLATURE

C_2	Pressure jump coefficien (m^{-1})
E	Energy(J)
$\vec{g}$	Gravity vector($m.s^{-2}$)
H	Height of the domain(m)
k	Thermal conductivity($W.m^{-1}K^{-1}$)
K	Turbulent kinetic energy(m^2s^{-2})
L	Length of the domain(m)
N	Air renewals (h^{-1})
$\vec{u}$	Velocity vector($m.s^{-1}$)

Vr	Air flow rate($m^{3/}s$)
Greek letters	
α	Permeability(m^2)
β	Coefficient of Thermal expansion (K^{-1})
ε	Turbulent kinetic energy dissipation rate($m^2.s^{-3}$)
θ_X	Angle between gravity vector and x-axis(Radians)
θ_y	Angle between gravity vector and y-axis (Radians)
θ_z	Angle between gravity vector and z-axis(Radians)
μ	Dynamic viscosity(Pa.s)
ν	Kinematic viscosity($m^2.s^{-1}$)
ν_t	Turbulent kinematic viscosity ($m^2.s^{-1}$)
σ_ε	Turbulent Prandtl number for ε (dimensionless)
σ_k	Turbulent Prandtl number for K (dimensionless)
$C_{1\varepsilon}, C_{2\varepsilon}, C_\mu$	Constant (dimensionless)
Subscripts	
f	fluid
t	Turbulence
eff	effective

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