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Computational Fluid Dynamic Analysis of a Greenhouse for Urban Farming

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ABSTRACT
Greenhouse engineering implementation along with thermodynamic condition maintenance can create a new revolution even in moderate climatic conditions of India, It can produce off seasonal crops and medicinal plants to reach required output healthy living our densely populated country. In this paper, the climate optimization problem in an innovative design made with glass greenhouse is studied with respect to the thermal behavior of geothermal heated greenhouses. The experimental greenhouse and the present report will be a useful tool in choosing the control system for it. The results obtained with the simulation system will also be helpful in convincing many other greenhouse engineers and entrepreneurs of India to successfully maintain thermal conditions of the greenhouse the most economical way to save energy and improve production by constructing properly designed high structures and control systems. The model includes the effects of solar radiation, cooling (with both a soil surface damping system and a heat sink cooling system in use when the outside temperature is high), Ventilation, infiltration, evaporation, and condensation. In this paper the dynamic simulation/ CFD Analysis will be presented, being the model used for modeling the green house. In addition to giving protection from the effects of wind, rain and snow, the temperature inside the greenhouse is increased during the day by solar radiation. As the rate of plam growth is doubled for a 10 K rise in temperature up to a certain limit, higher temperatures are important for the economic production of commercial crops in greenhouses, and some pretentious species require greenhouses to be heated at night as well as during the day. To predict the temperatures which occur naturally in a greenhouse, and the energy needed to achieve a desired temperature, requires an understanding of its thermal behavior.

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I. OBJECTIVE

The main objective of this research is to determine the heat absorbing capacity of the cooling pad and identify variation in heat flow among the various roof structures of greenhouse to ensure desired drop in room temperature by evaporative.

II. DESIGN CRITERIA OF GREENHOUSE STURCTURE

Dimensions of shed structure
Length = 1219cm, Width = 609.5cm
Height = 365.5cm
Wall thickness = 4mm of Glass / Polycarbonate sheets
Evaporative cooling Pad Dimensions
Material = Wood/ cellulose

1.1. CONSTRUCTION

Shape of the cooling pad will be corrugated to ensure maximum cooling in direct evaporative cooling system, in this system water is passed through the pipes and managed to flow through the corrugated cooling pads made of cellulose which is a porous biodegradable material and can hold cool water for maximum time period. Ambient air is passed through the evaporative cooling pads naturally for maximum air flow blower; fans are attached at the interior wall adjacent to the cooling pad which can direct more air flow through the cooling pad towards the interior side of greenhouse structure.

III. THEORETICAL CALCULATIONS

Thermal maintenance and engineering plays a vital role in greenhouse technology, and According to second law of thermodynamics it is known that heat flow or heat transfer is and endothermic process and thermal energy transitions will take place from hotter mass to cooler mass to reach thermodynamic equilibrium. Heat absorption in the cooling pad is determined by the equation:

$$Q = m \times c \times T$$

Further; In Greenhouse engineering the energy balance equations plays a vital role in the design and operation of greenhouses, Also; for dimensioning and heating installations, these energy balance equations occupies a central place. With this we can determine any changes in the greenhouse microclimatic condition, and there is possibility of determining the size of heat loss. In greenhouses, heat consumption is related to heat loss, which appears in the expression of equality:

$$Q_{cons}. = Q_{loss}$$

The higher the heat loss, the greater the consumption of heat is considered so, the energy balance can be simplified formula:

$$Qcons. = Qrad. + Qrad. + Qcond. – Qrad.s$$

1.2. Cooling system

Inside the greenhouse, the amount of cooling necessary for plant growth and development as for the normal biological Processes maintained by evaporative cooling system used. Hot ambient air is absorbed by the water flowing through corrugated evaporative cooling pads and the water is passed to flow towards heat sink filled with coolants such as solidified ice which makes water cool to recirculate through cooling pads, further air is blow inside using blower kept adjacent to the evaporative cooling pad, heat ceded from the ground as a result of radiation emission with longer wavelengths retained by the roof of glass or plastic will drop its temperature, In greenhouses coated with polyethylene there is a possibility in case of frost or during the night that temperatures will fall below values recorded in the atmosphere. This phenomenon of thermal inversion is explained by excessive transparency of polyethylene for long wavelength radiation is depending on the nature of the soil, wind action and building leaks. To avoid imbalance in evapo-transmission polycarbonate sheets are used with 4mm thickness instead of polycarbonate.

Heat balance equation for a time interval (0, τm) is represented as follows:

Qinc + Qr – Qs – Qc = 0 (3)

Where:

Qinc - the amount of cooling transferred by the cooling pads;

Qr - the average amount of heat for the period (0, τm) added to greenhouse by solar radiant energy;

Qs - the average amount of heat taken from the ground;

Qc - quantity of heat lost through building elements.

The heat balance components Qinc and Qr can be calculated with the following relations:

Qinc = qinc * S (4)

Qr = ϕ (1 – r) qrs * S (5)

Where:

S - Greenhouse area in m2;

φ - The transparency of glass in the visible range of the solar spectrum; r - surface albedo of building elements; qrs - the amount of solar radiation, the average for the time τm.

IV. CATIA MODAL

The **Version 5 Part Design** application makes it possible to design precise 3D mechanical parts with an intuitive and flexible user interface, from sketching in an assembly context to iterative detailed design. **Version 5 Part Design** applications will enable you to accommodate design requirements for parts of various complexities, from simple to advance.

This application, which combines the power of feature-based design with the flexibility of a Boolean approach, offers a highly productive and intuitive design environment with multiple designs Methodologies, such as post-design and local 3D parameterization. In this process, Initially Selected Start -> Mechanical Design -> Part Design from the menu bar and then Sketcher application is used to, make a possible 3Dsketch.

V. ANSYS

Ansys 15.0 Fluent analysis system is used for modeling water and air flow in cooling system and greenhouse,

COMPUTATIONAL FLUID DYNAMIC ANALYSIS RESULTS DETERMINATION USING ANSYS FLUENT

Adiabatic

The heat flux across the wall boundary is zero (that is, insulated). When radiation is included, the total heat flux is zero:

$$qw = 0 = qrad + qcond$$

Fixed Temperature

The wall boundary is fixed at a specified temperature. The heat flux into the domain is calculated for laminar flows from the temperature gradient at the wall, and for turbulent flows by:

$$qw = hc (Tw- Tnw)$$

Where Tnw is the near-wall temperature and involves the use of turbulent wall functions.

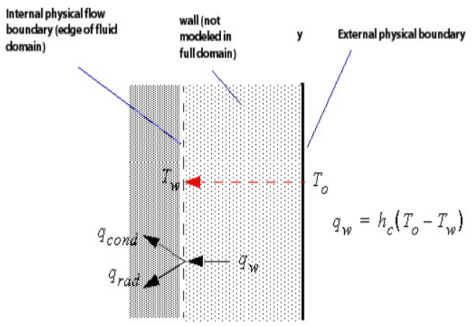
Heat Flux and Wall Heat Flux

A heat flux is specified across the wall boundary. A positive value indicates heat flux into the domain. For multiphase cases, when the bulk heat flux into both phases is set this option is labeled Wall Heat Flux instead of Heat Flux. When set on a per fluid basis, this option is labeled Heat Flux.

Heat Transfer Coefficient and Wall Heat Transfer Coefficient

The heat flux at a wall boundary is implicitly specified using an external heat transfer coefficient, hc, and an outside or external boundary temperature, To. This boundary condition can be used to model thermal resistance outside the computational domain, as in the diagram below:

Figure 2.4: Heat Transfer



The heat flux at the **Heat Transfer Coefficient** wall is calculated using:

$$q_w = h_c(T_o - T_w) = q_{rad} + q_{cond}$$

The heat flux at the Heat Transfer Coefficient wall is calculated using:

qw = hc(To – Tw) = qrad + qcond

Wall Temperature (Tw)

This is the hybrid temperature field at a wall boundary condition. For Fixed Temperature walls, the wall temperature is the specified value. For all other heat transfer boundary conditions, the wall temperature is backed out from turbulent wall functions when running a turbulent flow model. For laminar flow modeling the wall temperature is just the local fluid temperature at the vertex adjacent to the wall. When running the inhomogeneous heat transfer model, this variable is written per fluid.

Wall Heat Flux and Heat Flux (qw)

Wall Heat Flux is the total heat flux into the domain, including convective and radioactive contributions. There are also variables called Wall Convective Heat Flux and Wall Radioactive Heat Flux for the separate convective and radioactive contributions.When running the inhomogeneous heat transfer model, this variable is written per fluid. Similarly, for a porous solid, this variable is written for the solid phase as well.

Heat Flux is also the total heat flux into the domain, including convective and radioactive contributions. This variable is different from the Wall Heat Flux in several ways: There are no equivalent separate variables for the convective and radioactive components.

It can be plotted local to a specific boundary condition. Wall Heat Flux contains contributions from adjacent boundary conditions. For example, edge values of Heat Flux on a heat-transfer coefficient boundary are not affected by being adjacent to an adiabatic wall.

It is computed on boundary vertices by the post processor directly from the convective energy flows written to the results file by the FLUENT-Solver. This is sometimes advantageous over the Wall Heat Flux variable in that it eliminates the arithmetic averaging procedure used by the FLUENT-Solver to compute Wall Heat Flux at each boundary vertex from the faces adjacent to each vertex. Thus Heat Flux should be used in preference to Wall Heat Flux when this is possible.

In the FLUENT-Solver the heat flux variables available for use in expressions are just Wall Heat Flux and Wall Convective Heat Flux. These variables are based on energy flows and so are equivalent to the variable Heat Flux and its convective component in the post-processor.

Wall Heat Transfer Coefficient (hc) and Wall Adjacent Temperature (Tnw).These two variables are calculated as part of the convective heat transfer at a wall.

Laminar flow model

Wall Heat Transfer Coefficient, hc, is calculated by rearranging the expression for the convective heat flux and setting the wall temperature as described above.

Wall Adjacent Temperature, Tnw, is the average temperature in the element adjacent to the wall.

$$q_w = \frac{\tau_w c_p}{\Pr_t U}\left(T_w - T_f - \frac{\Pr_t U^2}{2 c_p}\right)$$

$$T_{nw} = T_f + \frac{\Pr_t U^2}{2 c_p}$$

Turbulent flow model

Wall Heat Transfer Coefficient is given by the thermal wall functions. For turbulent flow without viscous work active, the Wall Adjacent Temperature is the conservative (solved for) temperature in the control volume adjacent to the wall.

In fluent k epsilon modal is considered for this for analysis.

Wall Boundaries in Multiphase

For multiphase flows, it is convenient to enable two distinct methods for you to specify wall boundary conditions:

Bulk wall boundary conditions are defined as boundary condition attributes of the wall, and subsequently shared among the phases in a well-defined manner. The algorithm for sharing wall fluxes among fluids depends on the concept of a wall contact model (which will be explained shortly).

Alternatively, wall boundary conditions may be defined on a per fluid basis. This is a more advanced option, giving you complete flexibility in the definition of multiphase wall boundary conditions.

Bulk Wall Boundary Conditions

This is the simplest and most useful option. In most applications, wall boundary conditions are known as attributes of the wall. It is then part of the modeling procedure to decide how the consequent wall fluxes are allocated among the phases in contact with the wall.

A bulk heat transfer coefficient hwall and outer temperature To. The heat fluxes to each phase are determined as follows:

The difference between the specified wall temperature and the calculated phase temperature together with the heat transfer coefficient determines the heat flux to the phase. The contact area fraction is also taken into account.

A bulk wall temperature T_{wall}. The specified wall temperature is allocated to all phases in contact with the wall, and resulting wall heat fluxes are partitioned among phases using the contact area fraction. A bulk heat flux to the wall, Qwall. The heat fluxes Q alpha to each phase alpha is determined as follows:

$$Q_\alpha = A_\alpha Q_{wall}$$

Where is the contact area fraction of phase at the wall, calculated from the Area Contact Model as described below.

$$Q_\alpha = A_\alpha h_{wall}(T_o - T_\alpha)$$

Convective Heat Transfer

A - Surface area (m2) = 1
tsurface - surface temperature (oC) = 60
tair - air temperature (oC) = 45
hc - convective heat transfer coefficient = 80 (W/(m2K))
Convective heat transfer rate = 90000 w
Boundary conditions
Air Inlet = 45 Degrees
Air Outlet = 23 Degrees
Water flow on cooling pads = 18 Degrees

VI. CASE STUDIES

CASE STUDY 1: The structure is designed with conical weldments with a Glass panels run upto four sheds.

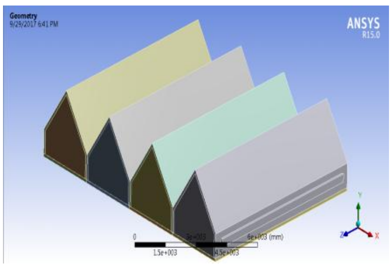


Fig.6.1: Geometric model of four sheds

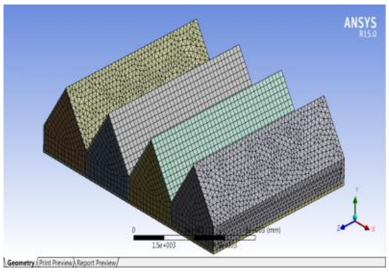


Fig.6.2: Fine Mesh generated by program

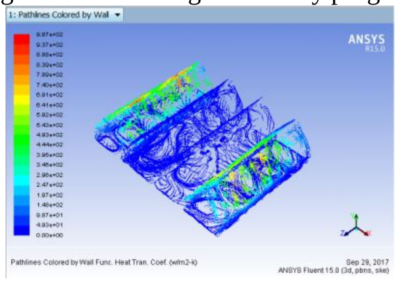
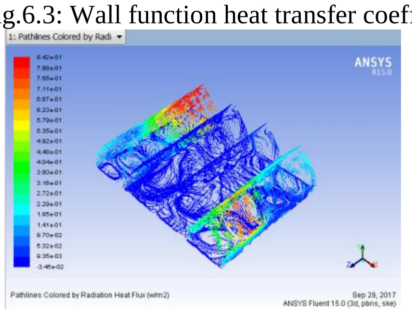


Fig.6.3: Wall function heat transfer coeff.



CASE STUDY 2: The structure is designed with a concrete wall and completely inclined roof and 1 m height small wall for lighting.

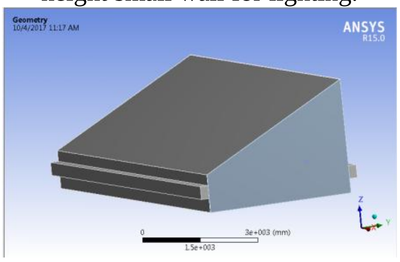


Fig.6.4: shows 3D Geometric modal

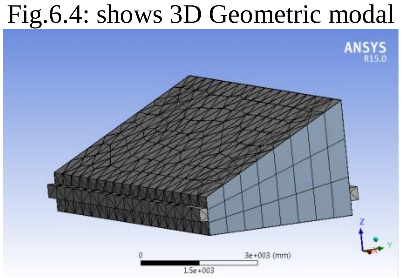


Fig.6.5: Innovative Greenhouse design

Air at 45 degrees is passed through the inlet part near concrete wall appearing taller at onside in the above figure, and outlet is considered at the opposite wall of the greenhouse in CFD analysis these selections are named to read as boundary conditions in post-processing stage in Fluent.

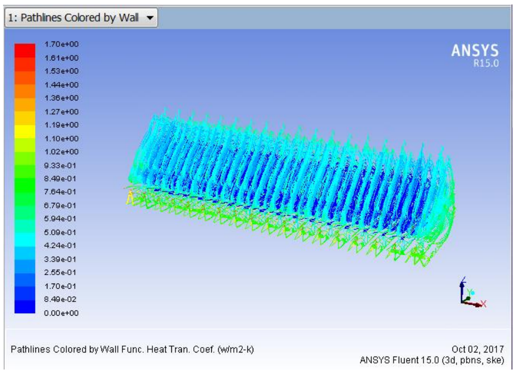


Fig.6.6: above shows wall function heat transfer coefficient

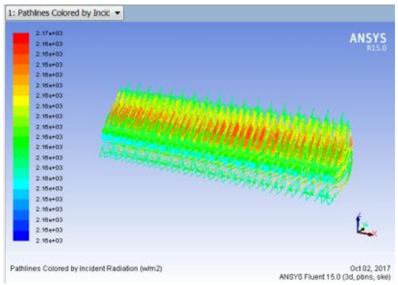


Figure 4: above shows Incident radiation of the Innovative modal.

CASE STUDY 3: The structure is designed with bended weldments with a polycarbonate sheets to cover the frames.

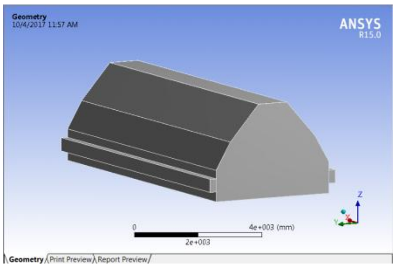


Fig. 6.7: Geometric mesh of Quonset modal

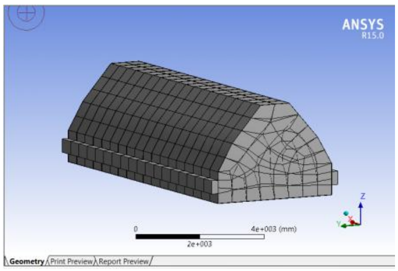


Fig.6.8: designed with bended weldments

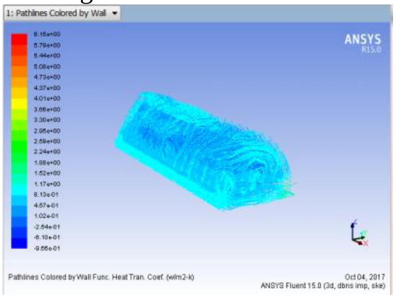


Fig. 6.9: Wall function heat transfer coefficient

VII. RESULTS

The computational domain, in which a CFD simulation will take place e.g. the greenhouse plus its environment, must be well defined. This domain is divided into small cells, the control volumes, in each of which a value for the simulated variables is calculated and conservation equations are applied to each of these control volumes. Rate equations define the transfer rate of a transportable property. The computational effort required can be large and is dependent on the number of computational cells in the domain, and the number of variables solved in each cell in the simulated transport processes.

VIII. CONCLUTION

In this research report various shed shapes are studied to analyze heat transfer rate among three different experimental modals, It is observed that Quonset greenhouse has less heat transfer rate when compared to other structures, so, it can be concluded as a best insulating shed with polycarbonate sheets for tropical regions like India.

TABLE 1: Wall function heat transfer coefficient

	Heat transfer(q)	Heat transfer coefficient (h)	Wall Thickness (t)	Wall function heat transfer	Wall thermal conductivity	Greenhouse Area	Change in temperature (ΔT)
	495	0.7	4’’	493	1.05	112	23
	172.5	0.4	4’’	173	0.8	56.27	23
	117.6	0.3	4’’	117	0.5	64	23

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