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Estimation of Various Loads of a Naturally Ventilated Saw Tooth Type Greenhouse

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ABSTRACT

Design loads of greenhouse include dead load, crop load, snow load, wind load and live load. The structural design of greenhouse must withstand from extreme combination of all types of load. In this paper, an attempt has been made to analyse the various loads of greenhouse. In India, the basic wind speed varies from 33 to 55 m/s. Along with wind speed, wind load also depend on the geometry, height to width ratio, effective frontal area etc. So greenhouse design should be customized as per the localized wind load. Among all the loads that act on the greenhouse, wind load is the major one (772 N/m^2). In this experiment, wind load for the saw-toothtype naturally ventilated greenhouse was estimated as per IS code 875 (part 3)and IS 14462: 1997. The design wind pressure estimated to be 772 N/m^2. The live load, crop load, truss load and load due to frame found to be 250,200, 250, 100 N/m^2 respectively.

Key words: *Basic wind speed, Design load, Greenhouse, Wind load.*

According to the Intergovernmental Panel on Climate Change (IPCC), if average atmospheric temperatures rise by 2°C, global food production potential will decline and particularly it will be pronounced in lower-latitude tropical regions. The combined effect of increasing population growth, strong income growth vis-à-vis limiting natural resources and changing climate necessitates protected cultivation and greenhouse is one such example. A typical greenhouse in India is basically steel tube structure covered by UV stabilized polythene sheet on top and insect proof screen on the sides. The area under greenhouses has increased at a CAGR of 49.16% from year 2007 to year 2012 with a present coverage of about 70,000 ha (IPCIO, 2015). However, due to non-availability of scientific guidelines, the growth has not attained its proper course.

The design load of a greenhouse includes the dead load (weight of the structure, equipment such as heating, ventilating, air circulation, electrical, lighting), live load (temporary loads such as the mass of repair crews and hanging plants etc.). Similarly it is also subjected to wind load, snow load, seismic load etc. Wind load depends on the basic wind speed, pressure coefficients and the shape of the greenhouse (Von Elsner *et al.*,2000, a and b). So the total load of greenhouse largely depends on climatic parameters of the locality. Hence, the wind load should be estimated precisely before designing the greenhouse. In India, most of the designsare more or less empirical, as a result many structures fail miserably as it happened recently in Madhya Pradesh. Under designed structures fails due to excessive loads whereas overdesigned structures are expensive. So an optimal design is the one designed as per the wind load of that particular locality and also considering the other loads with proper factor of safety. The estimation of wind load is essential for its safe and economic design. Minimum design load as prescribed IS 14462: 1997. However, the wind load need to be estimated before the design and installation of greenhouse as in a country like India, there is a huge spatial variation of basic wind speed through the width and breadth of the country. So, a single value of wind load may not hold well throughout the country.

The structural design of a greenhouse must provide safety from wind, snow, or crop load damage while permitting maximum light transmission. Therefore, opaque framing members should be ofminimum size while providing adequate strength to resist expected loads over the planned life of the greenhouse.

Green house practices across the globe: In France, there are altogether different standards for different kinds of greenhouse such as glass, multispan, tunnel etc. (CEN 1995, CEN 2001 and CEN 2003). Similarly, in Germany, depending on the geometric shape of the building, appropriate aerodynamic coefficients is standardized for surface of every sector of the structure. Moreover, in Greece, financing of greenhouses is subjected to approval of the structural design as per greenhouse specification with clear cut mention in the concentrated vertical load at various nodes, crop loads for various crops etc. In Italy, the building rules are adjusted for greenhouse despite the fact that building characteristics and uses are quite different from those of greenhouse. In Netherlands, a testing authority is set up to verify design calculation and to test specific construction details experimentally mainly due to frequent storms causing mechanical damages. Overall greenhouse design is strongly influenced by the climate. Moreover, various load requirements depend on climatic conditions. This is reflected in European National standard which is missing in Indian context. Much research has not been done so far in the way of analysing the various types of load and their distribution in the greenhouse. Existing Indian standards (IS 14462:1997-Recommendation for layout, design and construction of green house) unlike Eurocodes do not provide a methodology for the design of greenhouses. Limited information has been found in the international technical literature relevant to the calculation of loads for typical agricultural protecting structures such as greenhouse (Letchford, 2001), canopy roofs (Letchford, 2001) and tunnels and flat-roof structures (Robertson *et al.*, 2002). Research work concerning the analysis of the airflow through nets and meshes has also been published (Miguel *et al.*,1997). The earlier research work of has resulted few articles on the calculation of wind loads on agricultural protecting structures covered by nets, such as windbreaks (Ranga Raju *et al.*, 1988; Briassoulis 2003; Mistriotis *et al.*, 2006; Nayak, A K *et al.*, 2014) and canopy, flat and arched roofs (Mistriotis *et al.*, 2008)besides use of advanced irrigation systems among various crops (Bajpai and Saxena, 2017; Kishore *et al*., 2016; Saxena *et al*., 2015; Saxena *et al*., 2013; Saxena *et al*., 2006; Saxena *et al*., 2004).Therefore, the design is more or less empirical. Hence an understanding of various loads acts on the greenhouse is a prerequisite for design of greenhouse.

MATERIAL AND METHODS

Description of the greenhouse

The Study has been conducted in the Precision Farming Development Centre field, Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh. The greenhouse under study is a saw-tooth type, naturally ventilated greenhouse with 560 m^2 floor area (Fig. 1a &1b). The width and the length were 14m and 40 m respectively. The main columns were 76 mm outer diameter with thickness of 4mm. Total height of the structure was 6.5 m and the height of gutter was 4.5 m.Theoverall structure has been made up of 2 mm wall thickness and structural members are bolted. Columns were 76 mm outer diameter with 2 mm thick. Trusses and purlins were 33 mm outer diameter with 2 mm thickness. Telescopic foundation is common with 42 mm outer diameter and foundation depth of 76 cm. Foundation is grouted with cement concrete mixture of 1:2:4 using telescopic insertion. Telescopic foundation used in the greenhouse was bolted to the main column. Entire green house and the entrance room (size 3mx3mx3m) was covered with cladding material of 200 micron UV stabilized transparent polyethylene plastic filmconfirming IS standards (IS 15827: 2009). Two hinge doors are mounted of 2 m width and 2.5 m height.

Types of load

Dead load Design loads include the weight of the structure (dead load), loads brought on because of building use (live loads), and loads from snow and wind. Dead load depends on the framing, glazing system, and the amount of permanent equipment carried by the frame. For example, a pipe frame greenhouse covered with double polyethylene (PE) will have a much lighter dead load than a lapped glass greenhouse. Heating and ventilating equipment, water lines, etc., may add dead weight to the frame.

Live loads may be people working on the roof, hanging plants (if in place for less than 30 days), or other items carried by the frame for short periods of time. The dead load from pipe frame and truss found to be 100 and 250 N/m^2. As per standard IS 875 part 1, the minimum live load should be 250 N/m^2. Crop load from reference found to be 200 N/m^2.

Load transfer in greenhouse

First of all, wind load acts in the glazing. The glazing transfers the load to the primary members through glazing connectors and secondary members such as purlin members. The primary members (columns and trusses) transfer the load to the foundation then to the earth.

Wind Load

Basic wind speed

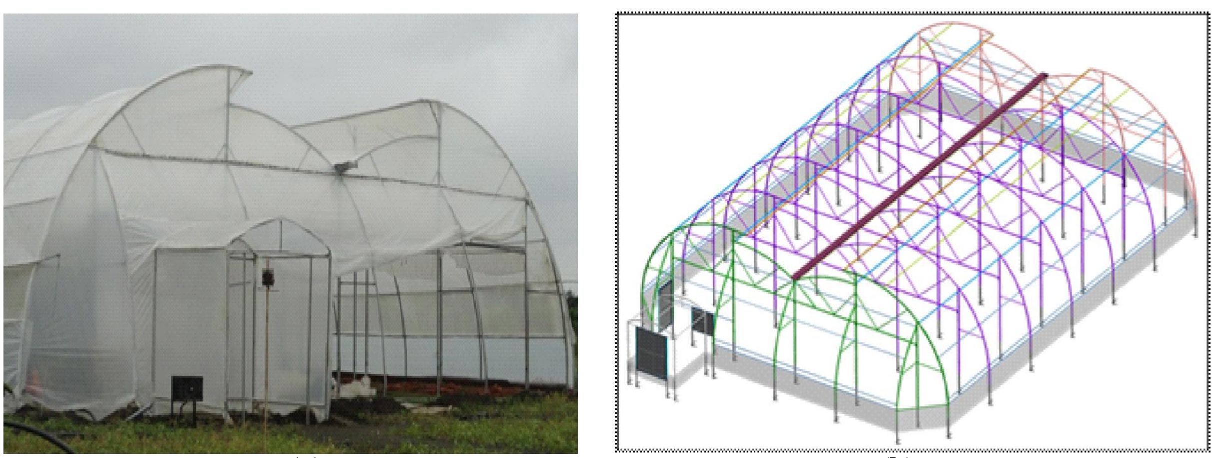
Basic wind speed is based on peak gust velocity averaged over a short time interval of

Table 1 Dimensions and various components of greenhouse structure

Component	Outer diameter (mm)	Thickness (mm)	Dead Weight (kg/m)
Main column (Small and big)	76	2	3.8
Big arc/Hockey/Top purlin/ Second purlin/ End purlin	60	2	3.1
Small arc	42	2	2.1
Truss	32	2	1.6

Table 2: value of external and internal pressure coefficient for a height/width ratio (0.5)

Roof angle	Wind angle (0°)		Wind angle (90°)	
	C_{pe}	C_{pi}	C_{pe}	C_{pi}
0	-0.8	-0.4	-0.8	-0.4
5	-0.9	-0.4	-0.8	-0.4
10	-1.2	-0.4	-0.8	-0.6
20	-0.4	-0.4	-0.7	-0.6
30	0.0	-0.4	-0.7	-0.6
45	0.3	-0.4	-0.7	-0.6
60	0.7	-0.4	-0.7	-0.6



(a) **(b)**

Fig. 1a. Saw-tooth type naturally ventilated greenhouse 1b. CAD design of greenhouse

about 3 seconds and corresponds to mean heights above ground level in an open terrain. Basic wind speeds have been worked out and estimated by the Survey of India for a return period of 50 years (Fig 2). Bhopal comes under Wind zone II with basic speed (V_b) of 39 m/s.

Terrain category

Selection of terrain categories was made with due regard to the effect of obstructions which constitute the ground surface roughness.Terrain Category 2 is open terrain with well scattered obstructions having heights generally between 1.5 to 10 m.

Design factor

Risk coefficient factor k_1 = 0.92 (for mean probable life of structure of 25 year)
Terrain and height factor k_2= 1(Class A structure)
Topography factor k_3= 1 (Upwind slope less than 3°)
Permeability of the building: Medium permeability as % open area is roughly 10 %.

RESULTS AND DISCUSSION

Design wind pressure

The design wind speed is the multiplication of basic wind speed, risk coefficient, terrain factor, topography factor and design wind pressure is 60 per cent of square of design wind speed.
Design wind speed= V_z= V_bx k_1xk_2xk_3= 35.88 m/s
Design wind pressure P_z= 0.6 $(V_z)^2$= 772.42 N/m^2

Internal Pressure coefficient

The pressure coefficients are always given for a particular surface or part of the surface of a building. The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient and the design wind pressure at the height of the surface from the ground. As per the code, buildings with medium openings between about 5 to 20 percent of wall area shall be examined for an internal pressure coefficient of +0.5 from inside and then for a suction of “0.5 from inside, and the analysis which produces greater distress of the members shall be adopted.

C_{pi} = ± 0.5

External pressure Coefficient

From the IS code, external pressure coefficient for double arch type structure is not available. Since it resembles circular section, C_{pe} is interpolated as -0.7 for the full width of the roof over half the length and for remaining portion is 0.5. The value of external pressure coefficient for different height/width ratio is presented in Table 2.

Design Pressure Coefficient for roof

Positive internal pressure will act towards the roof while negative internal pressure away from it. Hence positive internal pressure will be added to the negative external pressure coefficient and vice versa. The combination will have to be made separately. So the design pressure coefficient of the roof

C_{pnet} for roof= C_{pi}-C_{pf} = -0.7- (0.5) = - 1.2 (Suction)

= 0.5- (-0.5) = 1.0 (Pressure)

Wind load calculation

Wind load on the roof F = $C_{pnet}\, A_e P_z$
Where

C_{pnet} = net roof pressure coefficient= C_{pi}-C_{pf} ,

V_z = Design wind speed,

P_z= design wind pressure = 0.6 x V_z^2,

A_e = frontal area= 240m^2

Putting all the values, Design pressure on the roofs is -222.45 kN (Suction) and 185.376 kN(Pressure). So the roof must able to withstand this much wind load in any extreme event. And the wind load was applied from both X and Z direction as shown in Fig. 3 and 4. As the wind speed varies significantly with height so varying wind speed and corresponding wind load was applied on the greenhouse structure. Dead load of the total truss found to be 250 N/m^{2}whereas due to rest of the frame 100 N/m^2. Similarly crop load was taken as 200 N/m^2 whereas live load as 250 N/m^2.

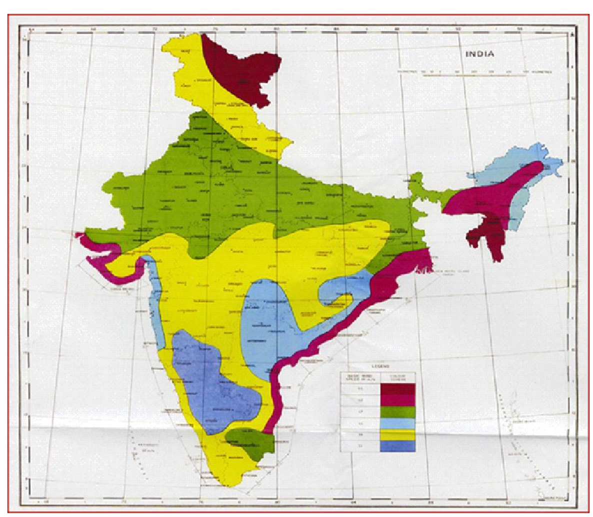


Fig. 2 Basic Wind Speed (V_b) in m/s

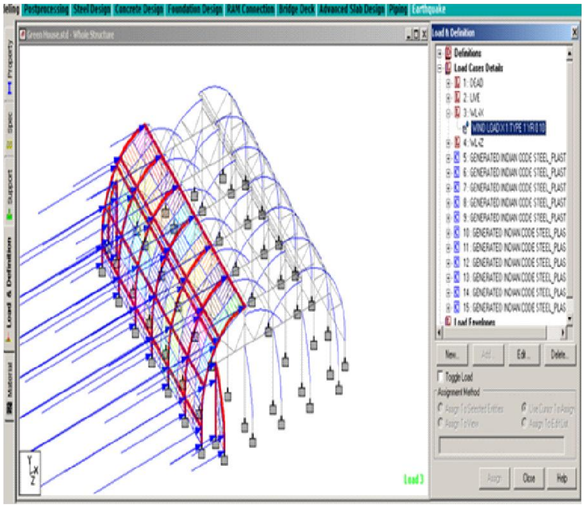


Fig. 3Wind load in X direction

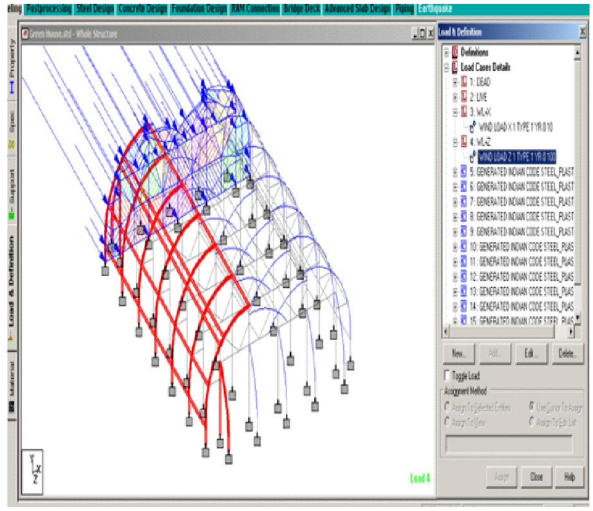


Fig. 4 Wind load in Z direction

CONCLUSION

While design of greenhouse, it should be ensured that the greenhouse can safely withstand this load combination along with suitable factor of safety.The wind load contributes more than 50 per cent of the total load in greenhouse in the Central India. In case of coastal area like Andhra Pradesh, it would be as high as 75 per cent as wind load varies with the square of the wind speed. The live load, crop load, truss load and load due to frame has been found to be 250,200, 250, 100 N/ m^2 respectively for a structurally safer green house.

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