Turbine ventilators installed on the roof of a factory for natural exhaust.

Industrial Ventilation Systems

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Ventilation system design for an industrial environment needs to be customized to fulfill specific requirements of each industrial application based on applicable design criteria in order to create a clean, safe and healthy work environment for better efficiency and productivity.

Techniques of design are evolved to work out solutions to industrial ventilation problems in different industries depending on diverse functional requirements. Here are some examples:

- Provide relief from excess heat generated in the work place by production machinery and processing equipment, through "local exhaust" of warm and polluted air directly at the source of heat and pollutants. A local exhaust system will require a hood to capture excess heat and pollutants and ducting to transfer warm and polluted air to the exhaust stack. Local exhaust ventilation reduces required exhaust air flow and also avoids spreading of contaminants from the polluting equipment to the entire workspace.
- A general exhaust system may be required to remove gases, vapours and other particulates from the entire work space since local exhaust might not capture all the contaminants from the workspace.

General exhaust ventilation also helps in removing excess heat from the work environment.

- Sufficient filtered make up air is to be supplied to replace the air extracted by local and / or general exhaust systems. If replacement air is inadequate, the inside pressure in the ventilated space becomes negative w.r.t. outside atmosphere which will trigger infiltration of outside unfiltered air through open doors and window cracks.
- In chemical plants toxic fumes may be generated. In such a situation efficient removal of toxic fumes will warrant design of a good stack height to avoid re-entry of polluted air. It may also be necessary to clean the exhaust air:

  i. In scrubbers to dissolve and remove such gases and vapours which are water soluble

  ii. Remove organic insoluble impurities through "adsorption" process by passing the contaminated air through activated carbon filters at low air velocity before discharging out to the atmosphere so as to meet Pollution Control Norms.
- In case of "air re-circulation" requirements, pollutants like powder dust (in certain applications) and fluff / lint, (as in case of textile mills)

About the Author

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will require dust collection and filters for air cleaning prior to re-circulation.

■ Ventilation for odour control from odorous chemicals, which may be emitted during chemical reactions in process industries. Removal of noxious odours from the work place may require deodorisation of exhaust air stream by using activated carbon filters or biofilters.

■ Indoor air quality & air movement : supply adequate volume of filtered fresh air in order to make-up for the air exhausted and satisfy not only the prescribed ventilation air flow rates for dilution of the carbon dioxide produced by the workers and maintain internal air quality norms as per ASHRAE standard, but also to provide adequate air changes and air movement at the occupied zone.

■ Pressurisation of ventilated area for dust control: often it is required to install forced draft supply air ventilation system with in-take air filters for pumping in fresh air at 10 to 15% higher flow rate than exhaust out flow in order to ensure slight positive pressure as required in the work place to prevent entry of outside dust.

Ventilation system for dust proofing of ventilated space may also require installation of air curtains at entry doors to prevent infiltration of outside air and dust during movement of men and materials.

Air Changes per Hour

Volume of ventilation airflow required for general ventilation for different industrial applications is expressed in terms of number of "air changes per hour" as a general guideline.

The required number of air changes per hour for different applications is shown in *Table 1* in a broad band as a general guideline. Higher rates of air changes indicated for each application are applicable for locations with high ambient temperature and higher internal load density so as to reduce supply air temperature rise and to dilute pollutants in the work environment.

Space to be ventilated		Recommended air changes per hour
• Factories (little heat & no fumes)	:	6 to 12
• Factories with high internal heat load generation from production equipment and densely occupied	:	15 to 30
• Machine shops	:	6 to 10
• Dye houses, spinning mills	:	20 to 30
• Warehouses	:	4 to 6
• Boiler houses, power houses and engine rooms	:	20 to 40
• Foundries	:	20 to 30
• Paint shops	:	30 or more

Table 1: Recommended air changes/hour for general ventilation

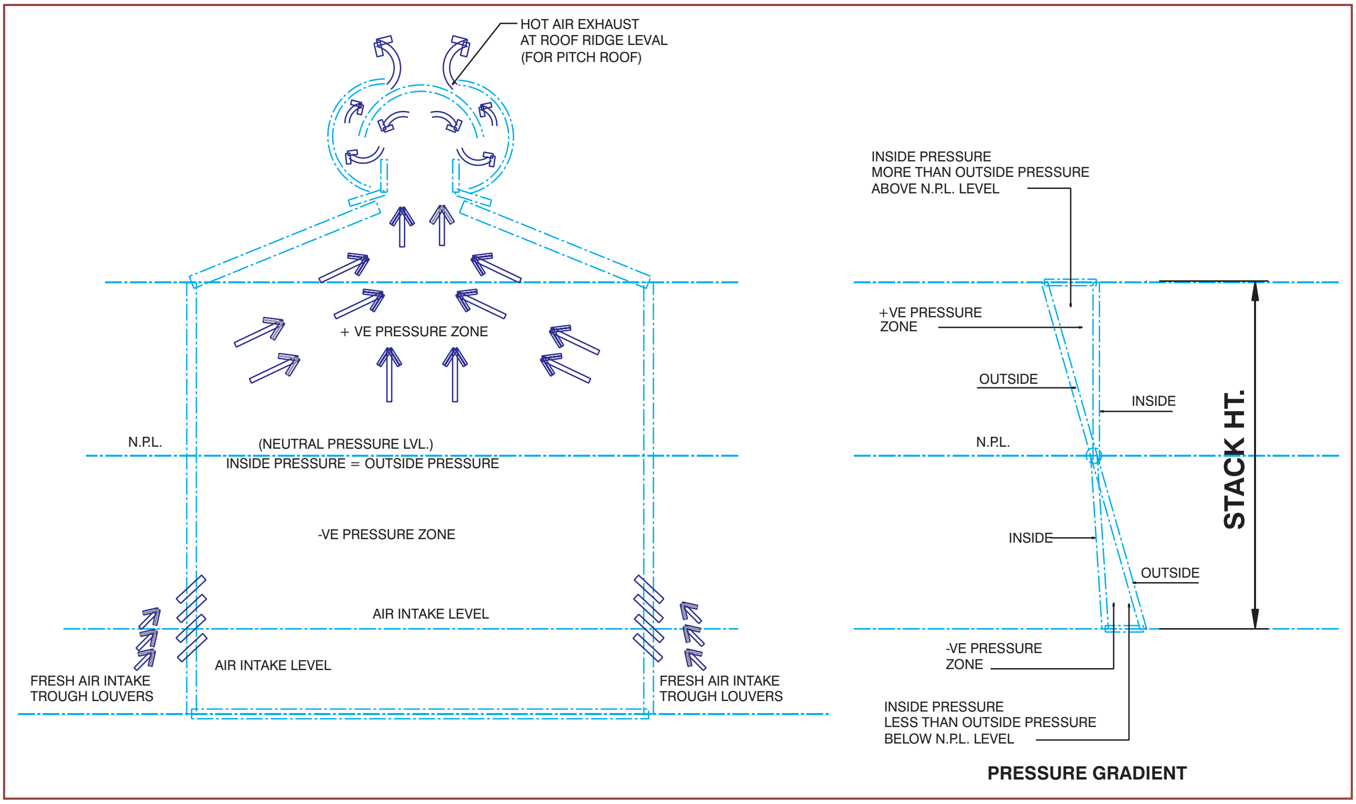

Figure 1: Natural ventilation system with air inlets located at low level below NPL for efficient natural ventilation.

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Types of Ventilation Systems

General ventilation systems for industrial sheds (with typical pitched roofing structure and metallic sheet / A.C sheet sloped roofing) may be designed for natural ventilation or mechanical (i.e. forced draft) fan driven supply and/or exhaust ventilation systems or hybrid system (i.e. combination of forced draft supply ventilation & natural exhaust ventilation.

A. Natural Draft Ventilation with Low-Level Intake Air Louvers for Fresh Air Supply and Roof Mounted Gravity Ventilators for Exhaust.

It is desirable to locate air inlet louvers at a low height of 2 to 2.5 m. from floor level so as to ventilate workers with fresh air at the operating level. As the inlet air warms up by picking up internal heat from the department, it becomes more buoyant and rises up to escape through throat openings in the "gravity ventilators" to the atmosphere.

Pressure gradient set up between inside and outside as shown in *Figure 1* results in natural air flow into the building at a level lower than the neutral pressure level (i.e. the level at which inside pressure is equal to outside atmosphere pressure) and warm / stale air is exhausted out through restricted openings of gravity ventilator at the high roof-ridge level due to inside pressure becoming more than the outside pressure at the upper levels. A view of a gravity ventilator fixed along the roof-ridge level of a typical factory-shed is shown in *Figure 2*.

Figure 2 : Natural gravity roof-ventilator.

Natural gravity ventilators (gravents) are made out of GI/aluminium/galvanized colour-coated sheets and fixed to roof panels at the ridge level. No outside air or rain water should enter through gravent openings. Typical general arrangement drawing of a 'gravity roof ventilator' is shown in *Figure 3*.

For optimum efficiency of natural ventilation, the net air intake area through louvres in the side walls of work space should be atleast 50% more than the total throat area (i.e. throat width × length of gravent) of roof mounted gravity ventilators for exhaust.

Design of Gravity Ventilator Size

The throat area of a gravity ventilator is usually worked out based on the required exhaust air volume

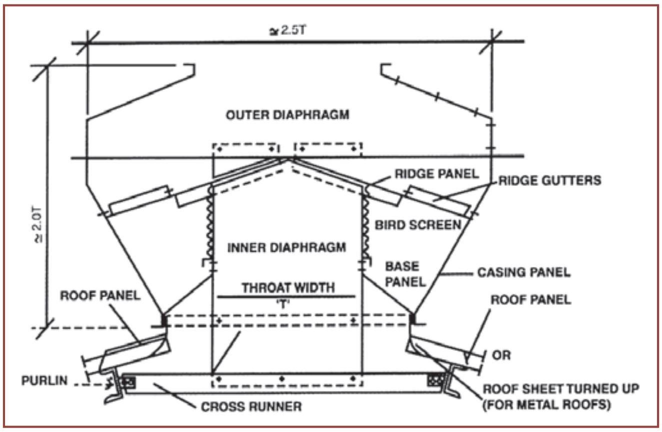

Figure 3: General assembly drawing of a gravity roof ventilator

flow rate, effective stack-height of gravent from centre point of fresh air inlets, design temperature rise of exhaust air compared to fresh air temperature (at inlet level) and design exit air velocity at throat of gravent. Typical design parameters for sizing of gravents are:

- 8°C to 10°C temperature rise of air at exhaust
- stack height approximately 7 to 8 m. and
- air exit velocity around 1.6 m/sec.

Based on these the required throat area a of gravity ventilator is worked out and based on the length of gravent (almost equal to the length of the shed) the required throat width is calculated.

Natural ventilation offers good scope for saving in energy cost. However, performance of natural ventilation may be affected with reduced wind-speed and change in wind direction, which may affect the pressure balance in the system.

Effectiveness of natural intake air ventilation also depends on the depth of the building w.r.t. ventilation openings. Single sided natural ventilation air intake is generally effective only upto a room depth of maximum 2.5 times the height of space and cross-ventilation is effective to a depth of about 5 times the height of space.

Industrial Turbine Ventilators

Some factory buildings located in areas with good natural breeze also use another system of roof-ventilators for natural exhaust with roof-mounted and wind operated light weight turbine ventilators of aluminium construction and aerofoil curved vanes which rotate due to dual effects of thermal convection current (on account of tem-

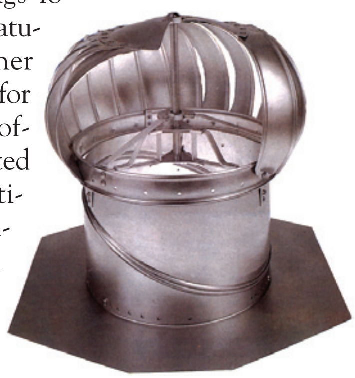

Figure 4: A typical turbo-ventilator

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Dry Bulb Temperature Deg.C		AIR VELOCITY MTR. / SECOND						
	% R H	30	40	50	60	70	80	90
28		*	*	*	*	*	*	*
29		*	*	*	*	*	0.06	0.19
30		*	*	*	0.06	0.24	0.53	0.85
31		*	0.06	0.24	0.53	1.04	1.47	2.10
32		0.20	0.46	0.94	1.59	2.26	3.04	+
33		0.77	1.36	2.12	3.00	+	+	+
34		1.85	2.72	+	+	+	+	+
35		3.20	+	+	+	+	+	+

* Minimum air velocity not a criteria
+Higher wind speeds than those specified in left hand column acceptable in practice.

Table 2: Desirable air velocity (m./sec.) for thermal comfort at different combinations of temperature and relative humidity

perature difference between bottom and top of the shed) as well as wind energy to eject hot air out of uniformly spaced multiple ventilators installed at the roof ridge level. A typical turbo-ventilator is shown in *Figure 4*.

Turbine ventilators help to save electrical energy as no electricity is consumed for spinning the rotary turbines.

Limitation of turbine ventilators is dependent on wind velocity and necessity of making many openings on the roof sheeting for fixing these ventilators.

B. Mechanical Ventilator & Mixed Mode Ventilation (Combination of Mechanical and Natural Ventilation)

For large span factory sheds, particularly with requirements of evenly distributed air flow and positive pressure inside for dust proofing, mechanical (forced draft) filtered air supply ventilation system with ducting for air distribution is a technical necessity.

In fact the Maharashtra Factory Rules 1963 stipulate that where the span of any work place exceeds 18 m. or where any work place is at a distance exceeding 9 m. from the ventilation opening at working level, additional ventilation by mechanical means is to be provided.

Some mechanical and mixed mode ventilation systems are described below:

(i) Mechanically driven (fan-driven) *'forced draft supply air dry or wet ventilation system* (comprising air in-take filters, axial flow / centrifugal fans with motor drive, air washer unit which is required if wet ventilation is desired for evaporative cooling, duct work and air diffusers for supply air distribution), working in conjunction with fan driven roof extractors sized for exhausting 80 to 90% of the designed supply air volume flow rate from the shop.

(ii) Mixed mode i.e. mechanical exhaust by fan motor driven roof extractors mounted on the roof ridge at required spacing for uniform exhaust from the shop floor, with *natural draft fresh air in-take louvers (for natural air supply)*.

Powered roof extractors are available with aluminum impeller or in fibre glass body and also provided with FRP rain protection hoods

(iii) Mixed mode i.e. mechanically driven forced draft supply air ventilation system (with equipment and accessories described in (i) above for ducted air supply to the shops) working in conjunction with natural gravity roof ventilators or wind operated turbo ventilators for air exhaust at roof ridge level.

(iv) Forced draft supply air ventilation system with air washer and ducting as in (i) above working in conjunction with mechanical return air fans, return air ducting, and return air filters (for cleaning the return air before recycling as in the case of textile mill

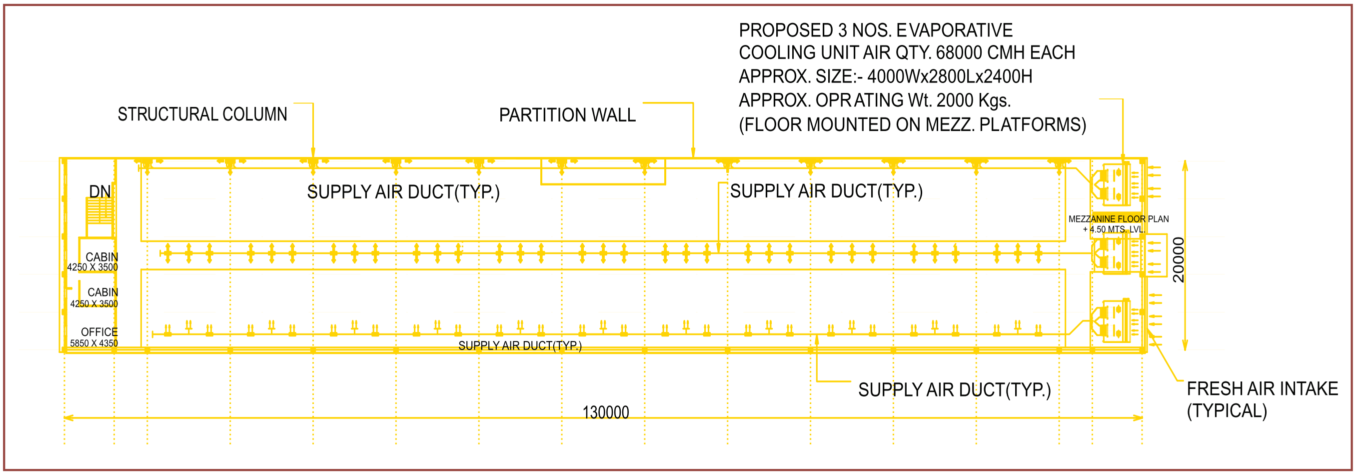

Figure 5 : Wet ventilation duct supply air system with platform mounted evaporative coolers.

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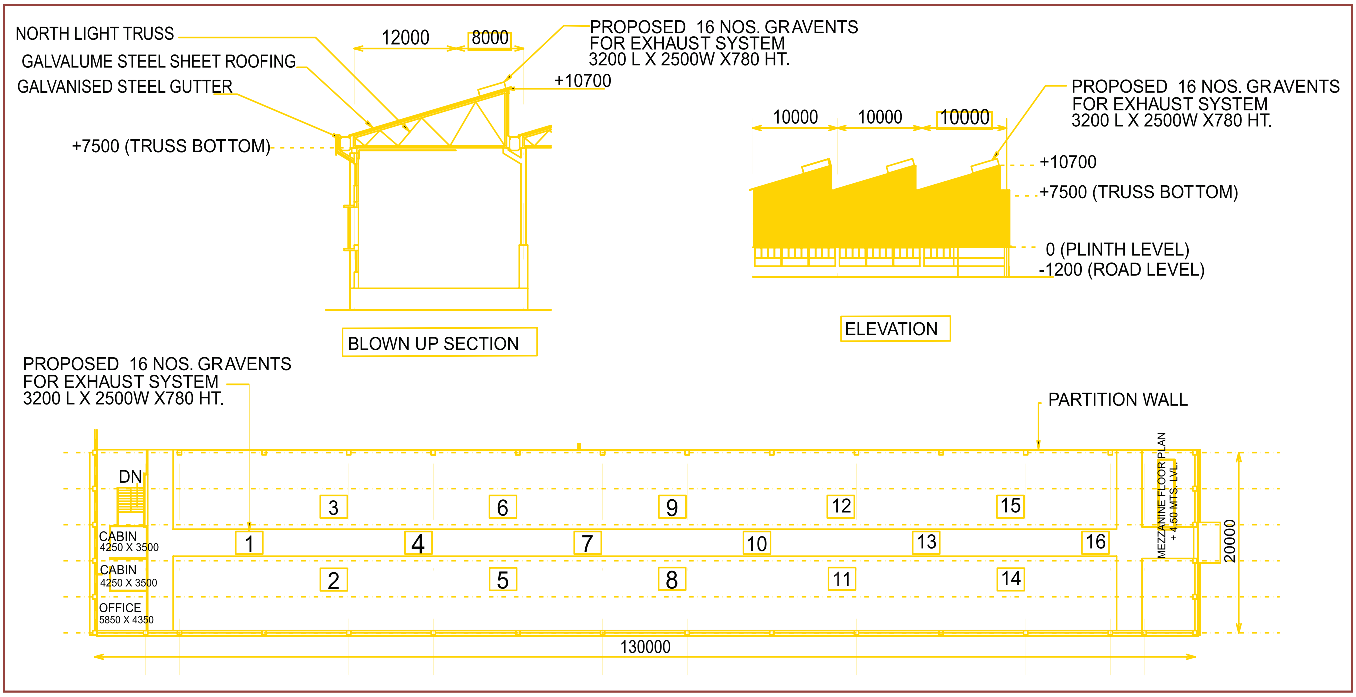

Figure 6 : Roof exhaust system with gravents

humidification applications.)

Mechanical supply air ventilation systems outlined in (i), (iii) and (iv) above provide uniform air distribution irrespective of seasonal climatic conditions, wind direction and velocity (unlike natural ventilation system where performance is affected by variation in outside climatic condition and changes in wind direction and wind velocity.)

Benefit of Wet Ventilation by Evaporative Cooling

Many factories at locations with long spells of hot and dry summer weather conditions deploy 'wet ventilation system' with air washer units for evaporative cooling of hot and dry outside air for lowering its dry bulb temperature before supplying to the workspace for ventilation with added benefit of relief to the workers from heat stress.

Typical arrangement of wet-ventilation system for a factory shed with platform mounted evaporative coolers and ducted supply air system for distribution of cooled air is shown in *Figure 5*. This mechanical wet ventilation supply system is to work in conjunction with natural gravity roof mounted ventilators as shown in *Figure 6* which are sized to exhaust upto 80% of supply air quantity.

Calculation of Air Volume Flow Rate in Wet-Ventilation

Based on typical summer outside design conditions of 104°F (40°C) dry bulb temperature and 76°F (24.4°C) wet bulb temperature for 'Pune' region, leaving air temperature from an air washer unit with 95% saturation efficiency works out to 104 – [(104 –76) x 0.95] i.e. 77.4°F (25.2°C.)

The cooled and humidified air at leaving air condition of 77.4°F (plotted on a constant wet bulb temperature line of 76°F on a psychrometric chart based on adiabatic cooling will be supplied in required volume flow rate to cope with estimated total RSH (Room Sensible Heat) including solar and transmission heat gains from walls, roof and glazing plus the sensible heat load from machinery, lights, blower-motors and other appliances. Delta T i.e. the temperature rise of cooled and humidified air leaving the air washer for maintaining inside conditions of approximately 90°F (32.2°C) dry bulb temperature & 63% RH is plotted on a psychrometic chart. The inside temperature of 90°F (32.2°C) with 63% RH achievable in dry summer months by evaporative cooling of outside air in an air washer, will provide adequate thermal comfort at a moderate air velocity of approximately 1.8 metres / second (350 fpm), (derived by interpolation from the *Table 2* of "Thermal Comfort Conditions" reproduced from "ISHRAE Handbook."

In a similar situation by using a dry ventilation system with un-treated outside air in summer, the inside dry bulb temperature will be more than the outside ambient temperature of 40°C due to air temperature rise on account of pick-up of dissipated heat from production and processing equipment.

Any relief to workers from thermal stress at such high

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temperature conditions in case of a dry-ventilation system will require a significantly higher air velocity at working level and consequently a larger volume flow-rate of ventilation air supply, as compared to a wet ventilation system. Effect of increased air-velocity will be an increase in convective and evaporative heat dissipation from the bodies of workers for relief from heat stress in a high temperature work environment.

Air Balance Between Supply & Exhaust

For any ventilation system to work at optimum performance level, a fine balance needs to be established between inlet air supply for make up and exhaust air out flow for removal of excess heat and contaminants. Generally the exhaust air flow rate is selected to exhaust around 80 to 90% of the supply air flow rate in order to maintain a slight positive pressure in the department w.r.t. outside atmosphere to prevent infiltration of outside dust and pollutants.

Kitchen Ventilation in Industrial Canteens

However, ventilation systems for kitchens in industrial canteens may be designed for higher exhaust air flow rate compared to supply air for make-up in order to maintain a slight negative pressure of 0.02 w.g. in the kitchen so as to prevent smoke, food-odours etc. from spreading to other areas.

Heat, smoke and other effluents such as grease particles entrained in the hot air collected in the "exhaust hood" located over ovens, fryers etc. will pass through baffle filters (to capture and remove grease particles).

Where odour control is required in addition to grease removal and for removal of soluble gaseous effluents, kitchen exhaust air after grease removal in baffle filters can be cleaned in a "scrubber" to entrap particulate matter and condense effluent vapours before discharging to the atmosphere by an exhaust blower.

Replacement Air for Make-up

In the case of a hood system for kitchen exhaust, the volume of air exhausted is to be replaced with uncontaminated fresh air for dedicated make-up. Make-up air supply either from outside or adjacent zone will prevent negative pressure from exceeding 0.02 inches of water gauge for safe operation of gas appliances.

Energy Conservation in Industrial Ventilation

The ventilation system for many industrial plants requires large air volumes to be circulated by mechanical (forced draft) dry / wet ventilation system for providing relief from large heat loads due to heat dissipated by production and processing equipment as well as solar and transmission heat gains through roof, glazings etc.

During the design phase of the ventilation system, insulation of roof, reducing the glass areas and radiation shielding of hot objects and surfaces like furnaces, ovens etc. for reduction of radiant heat-load will lead to reduced air quantities to be handled by the ventilation fans thereby reducing the electrical power to be consumed by the ventilation system.

The volume flow of air supply for a general ventilation system should, as far as possible, be distributed from a level of 2.5 to 3 m in order to ensure proper air movement at the occupied zone to reduce heat stress of workers.

If ventilation air supply is evenly distributed in the occupied zone at the working level, the required number of air changes per hour and the corresponding air volume flow rate can be based on a stratified height of 4.5 m or so instead of almost double the air volume flow rate that will result by considering the full height of the shed. The reduction in ventilation air flow rates based on stratified work space will reduce the power consumed by ventilation fans.

The volume flow rates of fresh air and exhaust air for general ventilation can be reduced in night shifts, winter and mild seasons due to reduction in heat load by shutting down one or more fans in a multiple-fan installation or by reducing blower speeds through VFD drive during part-load operations. ❖