Design of Apertures for Wind Induced General Ventilation in Industrial Buildings

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Control of contaminants in industrial buildings is necessary for the comfort and health of workers. This is usually effected, either by local ventilation or general ventilation. In the latter case air motion is supplied to the entire building. By handling large quantities of air. Thus the process, when carried out by a mechanical system, proves uneconomical because of high power consumption in operating air-moving appliances. However, in the tropics, moderately strong prevailing winds can be made use of for inducing general ventilation and thus contamination dilution can be accomplished economically. This necessitates optimization of the size of openings through which the desired quantities of air are to be moved. This forms the theme of this article.

Propagation and Control of Contaminants

Air-borne industrial contaminants produced in the form of gas, vapour, small dust or mist particles are generally smaller than 20 microns in size. These particles tend to ride over the air currents which are always present to some extent in factory buildings. The particles move almost at the mercy of the air currents and their spread is not influenced significantly by the force of gravity or diffusion. Accordingly the rate of removal of contaminants by ventilation is mainly governed by the rate of air flow through the building. Accumulation of contaminants is tolerable without any ill effects on workers so long as their concentration does not exceed a certain predetermined limit, known as maximuum allowable concentration (MAC). When the concentration of contaminants becomes greater than MAC then their dilution is necessitated. This can be accomplished through adequate general ventilation. For continuous ventilation the necessary rate of air flow may be computed using the equations.

$$Q = \frac{C}{c_{max} - c_{in}} \qquad (1)$$

$$Q = \frac{3.5\, H \times 10^6}{\Delta \theta} \qquad (2)$$

where Q = Desired rate of airflow M^3/h.

C = Volume of contaminant produced M^3/h.

c_{max} = MAC of contaminant in p.p.m.

c_{in} = Concentration of contaminant in the incoming outdoor air p.p.m.

H = Rate of heat libration Million K. cal/h

$\Delta\theta$ = Difference in temp. of outgoing and incoming air (°C).

Air flow due to wind force

The siting of a building in the path of wind currents obstructs the flow of wind causing displacement of streamlines. This results in the retardation of the air-stream on the windward face and enhancement of air speeds above the roof and along the sides of the building. Consequently over-pressure is created on the windward wall while the remaining walls and roof are subjected to reduced pressure. When openings are provided on the windward wall and leeward wall or roof, air flow takes place through the building. The rate of air flow may be calculated from the equation:

$$Q = C_e\, A\, V \sqrt{k} \qquad (3)$$

where Q = Volume of air flowing through the building M^3/hour.

C_e = Coefficient of flow

A = Total area of inlet in M^2

= Total area of outlet in M^2

V = Wind speed in M/hour

k = Dimensionless pressure ratio.

Factor Ce takes into account the resistance to air flow through the building caused by the shape of openings, the position of sashes when opened, the distance between openings, etc. For rectangular windows normally provided in factories, the value of C_e may be taken as 0.45[3]. The dimensionless pressure ratio, k, is the ratio of the pressure difference across the inlet and outlet openings to the free wind dynamic pressure. It is a measure of the effectiveness with which wind energy is made use of for inducing air motion indoors. For normal industrial buildings, with outlets in the roof lights and inlets located perpendicular to them on a wind facing wall, the value of k may be taken as 1.3[3]. For windows located on opposite walls, k assumes the value 0.8.

Determination of Area of Openings

Inducement of geneal ventilation by wind is achieved through openings of appropriate sizes located in the zones of positive and negative pressures. A knowledge of maximum allowable concentration of contaminant (Table 1)[4], its rate of liberation and outdoor wind speed make it possible to calculate[1] the desired area of openings in sq meters from the following equation:

$$A = \frac{2\ C \times 10^5}{V\,(C_{max} - C_{in})} \qquad (4)$$

A = Area (M²) of outlet located in roof lights assumed equal to the area of inlet located on the wind-ward wall perpendicular to roof lights

and $$A' = \frac{2.2\ C \times 10^6}{V\,(C_{max} - C_{in})} \qquad (5)$$

A' = Area (A²) of inlet on windward wall with an identical outlet on leeward wall

For the removal of excess heat liberated in the factory building, the required area of openings may be calculated by the equations

$$A = \frac{7\ H \times 10^6}{V\ \Delta\theta} \qquad (6)$$

$$A' = \frac{7.7\ H \times 10^6}{V\ \Delta\theta} \qquad (7)$$

(The values of $\Delta\theta$ may be taken from table[6] 2.)

For a contamination production at the rate of 1 metre³/hour, a quick estimate of the size of inlet located on the windward wall with outlet of equal size located tangentially in roof lights, can be made with the help of the nomograph portrayed in Fig. 1. For dilution of larger volumes of contaminants the area of openings obtained from the nomograph is increased proportionately. A further increase of 10% in opening sizes has to be made when outlets are provided on the leeward wall. The nomograph has been prepared assuming that the concentration of contaminant (Ci) in the

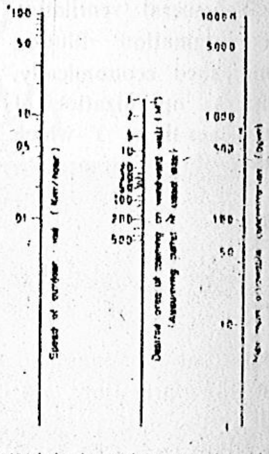

Fig 1 Nomograph for determination of area of [illegible] rate of contamination [illegible]

Table 1 : Maximum Allowable Concentration

S.N.	Substance	Permissible Concentration (ppm) (Parts permillion parts of air)
1.	Acetaldehyde	200
2.	Acetone	1000
3.	Ammonia	100
4.	Benzene	35
5.	1,3-Butadiene	1000
6.	n-Butanol	100
7.	2-Butanone	250
8.	Chloroform	100
9.	Carbon monoxide	100
10.	Carbon dioxide	5000
11.	Chlorine	1
12.	Cyclohexene	400
13.	Ethyl acetate	400
14.	Ethyl alcohol	1000
15.	Ethyl amine	25
16.	Ethyl Benzene	200
17.	Ethyl Bromide	200
18.	Ethyl Chloride	1000
19.	Ethyl ether	400
20.	Ethyl Formate	100
21.	Hydrogen sulphide	20
22.	Hexane	500
23.	Isopropyl Alcohol	400
24.	Isopropyl ether	500
25.	Methyl Alcohol	200
26.	Methyl Chloride	100
27.	Methyl Chloroform	500
28.	Nitrogen dioxide	5
29.	Octane	500
30.	Pentane	1000
31.	Propyl Acetate	200
32.	Sulphur dioxide	10
33.	Toluene	200
34.	Trichloro ethylene	200
35.	Xylene	200

outdoor air is negligible. For appreciable concentrations, the opening sizes are enhanced by $\frac{125\ C_{in}}{C/max}$ percent. However, for the contaminant concentrations normally encountered in the various Indian cities (Table 3)[6], the opening sizes determined from the nomograph agree well with these calculated from the mathematical equations.

The nomograph depicted in Fig. 2 determines quickly the desired area of roof and wall openings for removal of excess heat at the rate of 1 million kilo cal/hour. For other rates of heat generation the area has to be adjusted proportionately. Further, it is increased by 10% when openings are provided on opposite walls.

Discussion

Precise calculations of sizes of ventilation openings can be made with the help of mathematical equations derived from the knowledge of pressure distribution on factory buildings and basic principles of air flow through buildings. With less efforts, the opening sizes may quickly be determined with the help of nomographs also. The latter method is sufficiently accurate for practical purposes. It is worth mentioning that abnormally large areas (which may not even be feasible in practice) are necessitated for contaminants with low MAC, and also few low outdoor wind speeds.

Furthermore, natural ventilation depends on the mercy of the wind which is likely to be almost still for certain periods. Therefore natural general ventilation should be employed for contaminants with higher MAC values. When heat and obnoxious gases are liberated simultaneously, then the required areas of openings are first determined separately from the relevant nomographs and the greater of the two sizes is adopted for the desired ventilation. However, total reliance should not be placed on natural ventilation and exhaust fans should be provided somewhere in the roof lights as a stand by arrangement for contaminant extraction under calm conditions.

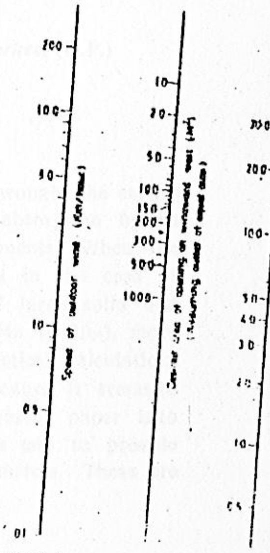

Fig 2 Nomograph for determination of area of ventilation openings for rate of heat liberation 1 Million Kilo Cal/Hour

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Table 2 : Allowable Temperature Rise Values

S.N.	Height of Outlet Openings (m)	Temperature Rise (°C)
1	1.5	2 to 3
2	6	3 to 4.5
3	9	4.5 to 6.5
4	12	6.5 to 11

Table 3 : Odour Concentration in Outdoor Wind

S.N.	Places	Substances		
		SO_2 (ppm)	NO_2 (ppm)	H_2S (ppm)
1	Kanpur	0.01	0.11	Not available
2.	Bombay	0.15	0.04	0.04
3.	Delhi	0.06	0.019	0.015
4.	Calcutta	0.04	0.034	0.01

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