9

GENERAL VENTILATION AND AIR JETS

9.1 Introduction

Whereas local extract ventilation is a reasonably well defined means of control, and can be described in both qualitative and quantitative terms, the concept of general ventilation is much less clearly defined.

It is usually dismissed as a means of effective control of airborne hazards, and grouped with personal respiratory protection amongst "other methods". However it does have a vital role to play and requires much more research and attention than it has been given to date.

The imprecise definition of the subject probably stems from its origin in the history of development of mechanical ventilation for buildings and for occupied spaces in buildings. But even here considerable controversy still exists between the "opening window" school and the advocates of sealed buildings with fully controlled environments.

It is not surprising then that the role of general ventilation to control airborne material emitted into workplaces, either as a supplement to local extract or on its own, is not clearly understood, nor always properly applied.

BRANDT (1947) suggests that a ventilation system can be regarded as "general" if the concentration of the contaminant in the air in the exhaust duct is not significantly higher than in the general room air. However, the term general ventilation is commonly construed to mean any ventilation that is not specifically intended to extract noxious airborne material at or near the source of its generation.

The term general ventilation can encompass both outdoor operations, such as occur on petrochemical plants, and enclosed space work, such as welding in pressure vessels. In the first case natural air movement is relied upon to dilute and disperse contaminant. Such air movement is highly variable and consequently the geometric standard deviation (GSD) of personal exposures measurement (15 minute Time Weighted Average) may be 4.5 or more. Under such circumstances the majority of the dose that operators receive will be due to the relatively infrequent but high peak exposures. By eliminating the sources of these peak exposures significant reductions in overall dose can be achieved.

Conversely in enclosed spaces there is little or no natural air movement and contaminant is released into a relatively small volume of air. Forced general ventilation is needed if high exposures are not to occur. In such operations exposures are relatively invariable (GSDs of 1.0 or more) and control of dose is therefore determined by the overall dilution efficiency of the applied ventilation.

The vast majority of operations in industry where general ventilation is applied lie between these two extremes.

9.2 Outdoor Ventilation

It is often assumed that if work is performed in open air, natural air movement will prevent overexposure. Thus people handle volatile solvents in open containers and even some routine operations such as fettling are carried out in open sided sheds. The point has already been made that outdoor air movement is highly variable. On some days there will be hardly any air movement at all and consequently little dilution and dispersion of the contaminant. Also, if a person works close to a source of contaminant the general dilution and dispersive effect of the wind may not offer the protection that many assume to occur. The person, especially if they have to work at a fixed position in relation to the process (ie they cannot move up wind) may be significantly exposed. Rather than assuming that exposure is automatically under control if work is done in the open air it is important to measure personal exposure, under the worst circumstances if possible, and check on the actual exposure reduction.

9.3 Indoor Ventilation

General indoor ventilation may be provided by systems designed to supply air to the workplace, or to extract it, or, preferably to do both. It may depend on a powered system or on natural forces of wind or heat, but frequently it is a mixture of both. It may be intended to provide outside (fresh) air to the work place to dilute any air contaminant present, or to displace contaminated air away from the areas where people may be exposed.

Further, there is a common complicating factor, which is the use of general ventilation as a means of maintaining suitable thermal conditions. In many cases, this is the prime role of general ventilation, with contamination control as an added benefit of uncertain or unknown value.

Guidance on minimum fresh air requirements for occupied areas where tobacco smoke is the principal contaminant, and which were originally based on the control of body odour, have been given by the Health and Safety Executive (1979). They also appear in a BRE Digest (1981), which includes formulae for calculating dilution of air contaminants though they are better presented in the Code of Practice BS 5925 (1980). The present Guide is principally concerned with air contaminant control and will not address questions of thermal conditions or fresh air requirements further. The interested reader should follow up the references cited.

9.4 The Work Environment

The advantage of first considering open air operations as one limit of general ventilation is that it is self-evident that the concentration of an airborne contaminant out of doors is not uniform. The same is true of airborne contaminants indoors though, unfortunately, this is often not appreciated. Rare examples of relatively uniform distribution of a contaminant within a working space are the diffusion of a vapour within a tank, or radon emitted from the ground or the walls of a building. More commonly, the concentration of airborne material inside a working space varies in time and position by several orders of magnitude, and it is not possible to quote a single value of concentration as a measure of hazard associated with working in that space. Sources may emit at cyclical or irregular intervals and some may be enclosed or partially controlled by local exhaust ventilation. There will be concentration gradients between sources and the general atmosphere of the workroom. Also, air currents and stable vortices within the building will produce a non-uniform concentration pattern within what would appear, at first sight, to be a homogenous volume of air. Approaching the use of general ventilation for air contaminant control with these factors in mind it is evident that simply introducing air into the general workplace, in an unplanned fashion, may have little or no effect on the exposure of workpeople, especially if they work close to sources of contaminant.

9.5 Dilution and Displacement Ventilation

Dilution and displacement ventilation are terms which are often used interchangeably as if they were synonymous. They are related but they are not the same. If the number and size of contaminant sources can be reduced (see Chapters 3.0, 4.0 and 5.0) it may be possible to control the remaining sources by local exhaust ventilation. However, this may not be possible or adequate. The sources may be too large in number or size and it must be remembered that no LEV is 100% efficient and some contaminant will escape and pollute the workroom air. To maintain workplace contaminant concentrations to within acceptable limits, even where LEV is applied to all the major sources, may require additional general ventilation. Usually such ventilation is seen as diluting the contaminated air. However, just as contaminant concentrations are not uniform within the work environment, so the dilution effect of injected fresh air will also not be uniform. Efficient mixing can be encouraged if care is taken in planning how air is going to enter and leave the workplace. Simply putting a few axial fans in the roof or walls with no thought to how air will gain entry to the work space is almost always inadequate and inefficient. Also as contaminant is usually emitted at certain positions in the workplace it may be possible to arrange for the general air movement generated by the planned input and output of air to sweep the contaminated air away from the work people. This is known as displacement ventilation and, though dilution of the contaminant will occur in the process, displacement reduces worker exposure by a different mechanism and should be distinguished from dilution ventilation. It may well be that CURD'S (1981) work on the use of wall jets can be adapted for use in producing stable displacement air movement across a work space. This idea of displacement of contaminated air can be carried a stage further into the field of air jets and douches. These methods are covered in Section 9.10 but firstly the calculation of the dilution of a contaminant and air change rates generated by wind and heat are considered.

9.6 Dilution Ventilation

As a general rule for high buildings containing hot processes, the natural ventilation rate is determined by the rate of heat release. For low buildings without major release of heat from processes, the ventilation is governed by the wind conditions. The principles of natural ventilation of buildings and a guide to design is given in the Code of Practice BS 5925 (1980) which should be consulted if detailed knowledge is required. It provides the basic data for calculating the dilution of airborne substances by the provision of general ventilation.

The required standards that have to be met are for:

Human respiration
Dilution and removal of odours, tobacco smoke, toxic and flammable gases and other contaminants
Control of internal humidity
Provision of air for fuel burning appliances
Control of thermal comfort
Clearance of smoke resulting from fire.

It can be seen immediately that control of air contaminants is only one factor that must be considered in designing general ventilation systems for workplaces, although contaminant control is the main subject of this Guide.

The British Standard provides a method of calculating the supply rate of outside air that is needed to limit the concentration of a contaminant, providing that good mixing takes place within the ventilated space.

It must again be emphasised that this is not appropriate where a worker is exposed close to a source of contamination, before the contaminant is diluted, though factors to allow for this can be introduced.

General Ventilation

In the simplest situation where there is a single release of contaminant which disperses uniformly in the work space and is diluted by clean incoming air, the rate of decay of concentration is given by:

$$c = c_o e^{-Rt}$$

where:

c_o = initial concentration of contaminant in air by volume
R = ventilation rate = Q/V
Q = volumetric flow of clean incoming air (in $m^3 s^{-1}$)
V = volume of ventilated space (in m^3)
t = time (in s) from when the contaminant fills the space

Where a contaminant is released into the space at a constant flow of q (in $m^3 s^{-1}$), and disperses uniformly the concentration at time t after release commences is given by:

$$c = \left[\frac{1}{1 + Q/q}\right] 1 - e^{-\left[\frac{(1 + Q/q)\,qt}{V}\right]}$$

The rate of airflow Q required to give the equilibrum concentration C_E where the concentration in the incoming air is C_e

$$Q = q\left(\frac{1 - C_E}{C_E - C_e}\right)$$

and the equilibrium concentration is given by:

$$C_E = \left(\frac{QC_e + q}{Q + q}\right)$$

It should be noted that if the incoming air is free of contaminant, then the equilibrium concentration = q/(Q + q), and is independent of the building volume. The building volume affects only the rate at which the equilibrium concentration is approached. If the volume of the contaminant is insignificant relative to the volume of clean incoming air then the equilibrium concentration becomes q/Q.

The Code of Practice BS 5925 (1980) refers to the TLV limits of contaminants but more recent information is available on Control and Recommended limits HSE (EH40). It is also noted that some gases and vapours differ considerably in density from air, and may produce regions of dangerously high concentration despite a ventilation rate that is theoretically sufficient (see Chapter 3.0, section 3.3.2 for further details). Finally, the use of ventilation is considered to control smoke generated in a fire which otherwise may hinder escape, rescue and fire-fighting. The point is made that the requirements for ventilation in the event of fire may, on occasion, be incompatible with those for normal ventilation.

9.7 Calculating the Rate of Natural Ventilation

The rate of natural ventilation can be estimated if the size and location of openings in building structures are known, and if certain meteorological and building thermal factors are taken into account. Before considering these it is important to stress that any form of natural ventilation is highly variable so that control of contaminants is itself variable, with the control being achieved only on a statistical basis. Accordingly, in general, natural ventilation should not be relied upon to control contaminants which present a hazard of acute poisoning, for example, hydrogen sulphide. Nevertheless, it can make a very significant reduction in the average exposure to contaminants that present long-term risks. The Code of Practice BS 5925 (1980) lists situations where mechanical ventilation is absolutely necessary and those where it is desirable.

In addition to the information that follows, the Code of Practice includes other formulae and diagrams (for example, to calculate directly the flow rate from difference in the wind pressure across a building, taking account of its length and breadth, its shape, and the direction of the wind, as well as the shape of the openings). There is also detailed advice on its application and limitations.

The following comprises a "back-of-envelope" system for very simple calculations of flow rates in buildings to enable an initial assessment of the likely diluted concentration to be estimated. Far more precise systems of calculation based on the Code of Practice BS 5925 (1980) are possible and may be used by ventilation consultants and building designers. The validity of some of the assumptions has not been determined, and for the occupational hygienist it is doubtful if more precise theoretical calculations are justified in the absence of practical confirmation of their validity.

Meterological variables to be considered are wind speed and external temperature. Mean wind speeds at a standard height of 10 m above ground level have been determined for a large number of sites in the UK, varying over hourly periods from about 4 ms^{-1} in central areas to 6 ms^{-1} at coastal sites, and information is given on the distribution of wind speed with time. For example for 80% of the time, the speed is greater than 0.56 of the mean speed at exposed coastal sites and 0.46 at sheltered inland sites. The converse is important in the control of contaminants, that is, for 20% of the time wind speed is less than about one-half of its mean value. Roughly then, wind speed can be taken to be 2-3 ms^{-1} for 20% of the time.

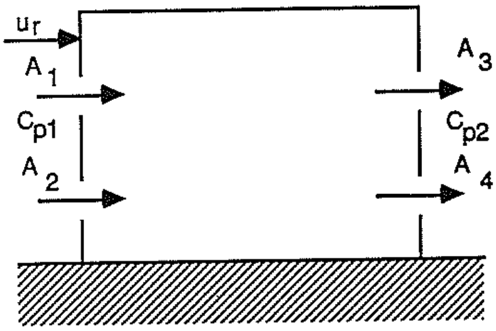
The actual wind speed impinging on a building varies with the atmospheric stability and local topography. From a table in the British Standard it is possible to deduce that, for a low industrial building in a city, the reference wind speed impinging on the building may be only 0.3 of the above values, that is rather less than 1 ms^{-1}, whereas for a 25 m high building in open country the corresponding wind speed is about 1.2 ms^{-1}.

It is then shown how the mean surface pressure coefficients can be estimated for various ratios of building height and plan, and the angle at which the wind impinges on the building. Generally, the difference between the coefficients for the upwind and downwind sides of a building is about 1.0.

The Code emphasises that calculation with any degree of precision requires digital computation and that several programmes are available; however it does provide some simplified models. These are illustrated below.

General Ventilation

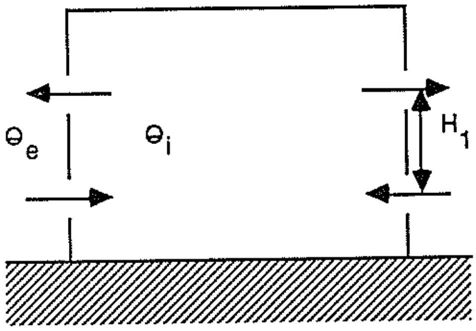
Wind only



$$Q_w = C_d A_w U_r (\Delta C_p)^{1/2}$$

$$\frac{1}{A_w^{\,2}} = \frac{1}{A_w^{\,2}} = \frac{1}{(A_1 + A_2)^2} + \frac{1}{(A_3 + A_4)^2}$$

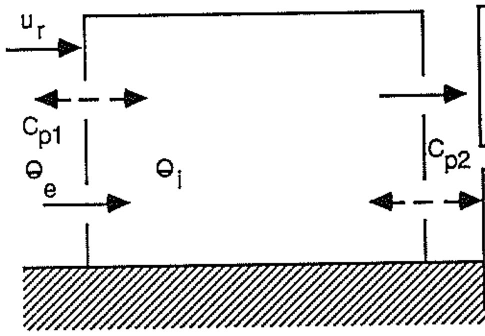
Temperature difference only



$$Q_b = C_d A_b \left[\frac{2\Delta \Theta g H_1}{\bar{\Theta}}\right]^{1/2}$$

$$\frac{1}{A_b^{\,2}} = \frac{1}{(A_1 + A_3)^2} + \frac{1}{(A_2 + A_4)^2}$$

Wind & temperature difference together



$Q = Q_b$ when $\frac{u_r}{\sqrt{\Delta \Theta}} < 0.26 \left[\frac{A_b}{A_w}\right]^{1/2} \left[\frac{H_1}{\Delta C_p}\right]^{1/2}$

$Q = Q_w$ when $\frac{u_r}{\sqrt{\Delta \Theta}} > 0.26 \left[\frac{A_b}{A_w}\right]^{1/2} \left[\frac{H_1}{\Delta C_p}\right]^{1/2}$

Q = volume flow rate of air
Q_w = volume flow rate of air due to wind only
Q_v = volume flow rate of air due to temperature difference only
A = equivalent area of openings (m^2)
C_d = discharge coefficient of openings
C_p = surface pressure coefficient
u_r = reference wind speed (m/s)
ΔC_p = difference between surface pressure coefficients on upwind and downwind sides of building
H_1 =difference of height between upper and lower openings
$\Delta\theta$ = difference between outside and inside temperature (^oC)
$\bar{\theta}$ = average of outside and inside temperature (^oK)
θ_e = absolute temperature of outside air
θ_i = absolute temperature of inside air

(For simplified calculation, assume: $C_d = 0.6$, $\Delta C_p = 1.0$)

General Ventilation

Simplified Worked Example

What is the minimum ventilation rate due to wind for 80% of the time in a factory building 10m high, with openings facing the prevailing westerly wind of 2m (low level) and 3m (high level), separated by a height of 5m? The building has similar openings on the opposite side.

The building is loacated:

(a) in an inland city
(b) on an open site in flat country

Further, in the absence of wind, what is the ventilation rate if the mean daily outside temperature is 5^oC, and the average internal temperature 25^oC. What is it when the outside temperature is 20^oC and the differential only 5^oC?

First determine the equivalent area of opening, for wind effect:

$$\frac{1}{A_W^2} = \frac{1}{(A_1 + A_2)^2} + \frac{1}{(A_3 + A_4)^2} = \frac{1}{(2+3)^2} + \frac{1}{(2+3)^2} = \frac{1}{25} + \frac{1}{25}$$

$A_W^2 = 12.5$ $A_W = 3.5m^2$

Calculation of flow rate:

In inland city $u_r = 0.8$

$C_W = C_d\, A_w\, u_r\, (\Delta C_p)^{1/2}$
$= 0.6 \times 3.5 \times 0.8\ (1.0)^{1/2}$
$= 1.7\ m^3/s$

Open site flat country $u_r = 0.8$

$C_w = C_d\, A_w\, u_r\, (\Delta C_p)^{1/2}$
$= 0.6 \times 3.5 \times 1.2\ (1.0)^{1/2}$
$= 2.5\ m^3/s$

Temperature effect

Calculation of equivalent area:

$$\frac{1}{A_b^2} = \frac{1}{(A_1 + A_3)^2} + \frac{1}{(A_2 + A_4)^2} = \frac{1}{(2+2)^2} + \frac{1}{(3+3)^2} = \frac{1}{16} + \frac{1}{36}$$

$A_b^2 = 11.0$ $A_b = 3.3m^2$

Calculation of flow rate

Assuming 20^oC differential

$$C_b = C_d A_b \left[\frac{2\Delta\theta g H_1}{\bar{\theta}}\right]^{1/2}$$

$$= 0.6 \times 3.3 \left[\frac{(2 \times 20 \times 9.8 \times 5)}{300}\right]^{1/2}$$

$= 5.1\ ms^{-1}$

Assuming 5^oC differential

$$C_b = C_d = A_b \left[\frac{2\Delta\theta g H_1}{\bar{\theta}}\right]^{1/2}$$

$$= 0.6 \times 3.3 \left[\frac{(2 \times 5 \times 9.8 \times 5)}{300}\right]^{1/2}$$

$= 2.5\ ms^{-1}$

The calculations indicate that with the ventilation openings assumed in the example, even at an exposed site and with an average temperature inside the building only 5°C above ambient, the difference of temperature has more effect on natural ventilation than wind forces for about 20% of the time.

The example can be extended to demonstrate calculation of vapour concentration arising from evaporation of products, it being assumed that the primary source of vapour release at the manufacturing process is controlled by local extract ventilation. Perhaps material is stored in an area away from normal occupation but the vapour disperses uniformly into working areas. For the purposes of example, it is assumed that 0.01 litre/s of solvent vapour continues to disperse during storage. What will be the equilibrium concentration if there is little wind?

From the calculated ventilated rates, it appears unlikely that the flow of fresh air will be less than 2.5 ms^{-1}, so the equilibrium concentration will be:

$$= \frac{0.01 \times 10^6}{2.5 \times 1000} \text{ parts per million (ppm)} = 4 \text{ pp}$$

In a similar way the diluted concentration can be calculated from known evaporation of a volatile substance, such as a solvent from paint. As the corollary, the flow of air needed to dilute a known rate of evaporation of a substance down to the control or recommended limit can be calculated.

In a practical form the formula for this is:

$$Q\,(m^3s^{-1}) = \frac{\text{Rate of evaporation } (mg\,s^{-1})}{\text{Density of the liquid } (kg\,m^{-3}) \times \text{limit in ppm}}$$

Concentrations close to the source are likely to be much greater than this, and it is the practice in the United States (ACGIH, 1984) to introduce a multi-purpose safety factor "K" to allow for non-uniformity of concentration in the building, both in space and time, and for the toxicity of the material. A value for K of between 3 and 10 is selected on the basis of experience, and is usually applied to the calculated flow of ventilation air needed to dilute a known release of solvent down to the threshold limit value (TLV) in air. It must be recognised as a rough and ready rule, that can only be justified in the absence of better techniques of assessment, and should be followed up by personal air sampling to determine actual exposures of workers.

Initial assessment may also be made on the basis of the known vapour pressure of a liquid producing a hazardous vapour. In its simplest form, if it can be shown that the vapour pressure of a liquid is low at the temperature of use then a hazardous concentration in air is most unlikely. An example of such a substance is trimethylbenzene. At the other extreme, a substance like benzene (C_6H_6) has a vapour relatively high pressure and hazardous concentrations of vapour are highly likely to occur if proper controls are not instituted (see Chapter 3.0).

Throughout these calculations, the general ventilation rate has been described in terms of the volumetric rate of flow (m^3s^{-1}). It is also commonly expressed in terms of the number of times the air is changed within the space in unit time (ie air changes per hour).

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$$\text{Air changes per hour} = \frac{\text{Volumetric flow rate } (m^3s^{-1}) \times 3600}{\text{Volume of space } (m^3)}$$

This is the conventional unit employed by the ventilating engineer who uses (or, at least, used in the past) standardised assumed values of air change rate to calculate winter heating requirements of various types of buildings.

9.8 Theory and Reality

The dilution effect of general ventilation can be measured by monitoring the fall in concentration of a harmless tracer gas (sulphur hexafluoride is often used). Though how to relate these fixed point "air change rates" generated by such procedures to likely personal exposure is difficult. Also it may be possible where displacement ventilation is contemplated to calculate the likely concentration "downwind" of an isolated source provided suitable diffusion coefficients can be selected and the emission rate of the source is known. But because of the many unknowns and rough assumptions involved the theoretical effect of natural and forced general ventilation should always be checked by personal and static air sampling.

9.9 General versus Local Exhaust Ventilation

If exposure from the same process is controlled with a similar degree of efficiency by local and general ventilation it is found that the air volumes, and therefore the running costs (in a temperate climate), of the general ventilation far outstrip the LEV. Also, in practice, simply relying on general dilution ventilation by itself to control exposure is found to be of limited effectiveness.

GOLDFIELD (1980) examined the effectiveness of general ventilation in relation to local extraction in the manufacture of asbestos. He concludes that the effectiveness of general ventilation in reducing worker exposure to air contaminants appears to be minimal. Local exhaust hoods were found to produce much more effective control near intermittent dust sources, and the contribution of general ventilation rates of four and ten changes per hour was found to be negligible.

Thus, general dilution ventilation is not the method of first choice for air contaminant control. In some instances it may, in practice, be the only choice and should be supplemented by planned displacement and the use of air jets or air douches (see section 9.10). In many instances general dilution and local exhaust ventilation have an interactive and complementary role. This is well illustrated by work done on the control of carbon monoxide exposure in motor vehicle garages.

At fixed and identifiable positions the vehicle engines are run for test purposes, and local extract should be provided to remove the exhaust fumes. If the extract can be connected to the vehicle exhaust, the volumetric flow need be little more than the flow of the exhaust gases, that is of the order of 0.05 m^3s^{-1} for each vehicle on test. If the use of these is not practicable then it may be necessary to provide an extract point in the vicinity and a much greater volumetric flow of air will be required.

During the course of servicing, the vehicles need to be moved within the building and, it is not then feasible to apply local extract and general ventilation must be used to prevent the build-up of hazardous concentrations and to discharge the dilute gases from the building.

A detailed study has been published in the USA (HAMA and BUTLER, 1967) which provides a seven point summary of requirements. These include recommended airflows of about 0.1 m^3s^{-1} for each local exhaust extract and 0.25 m^3s^{-1} per vehicle of general ventilation. A building volume about 250 m^3 was recommended to cushion CO build-up during periods of intense activity. Recent US practice (ACGIH, 1984) generally follows these standards but a general ventilation rate of 2.5 m^3s^{-1} per vehicle is now recommended. Guidance for control of atmospheric pollution in UK car parks is offered by HSE in EH33.

Thus in order to control exposure to carbon monoxide (CO) effectively LEV is applied where feasible but the designer has to recognise that some CO will escape the LEV and that there are operations where LEV cannot easily be applied. In order to dilute the CO produced by these operations a minimum amount of general ventilation, in terms of fresh air per vehicle, is recommended. How effectively this fresh air is in reducing the concentration of residual CO will depend on how well the input of this replacement or "make-up" air is planned. The work of ROACH (1981) illustrates how important it is to ensure that replacement air is introduced throughout the body of an occupied space and not simply at its periphery. The need to make optimum use of replacement air leads the discussion of general ventilation logically on to the use of air jets and air douches.

9.10 Air Jets and Air Douches

The use of air jets in the form of air curtains coupled with a receiving hood, in what are known as "push-pull" systems, is covered in Chapter 7.0. This section is concerned with the use of free-air jets to enhance the effectiveness of general ventilation.

9.10.1 Air Jets - A Description

The motive force which propels air out of a jet nozzle is derived from the pressure difference between the jet supply duct and atmospheric pressure. As the air under pressure leaves the nozzle it expands. For instance, a circular nozzle will produce a cone diverging from an axis along its centre line by about 18°. At the periphery of the moving jet of primary air the relatively stationary room, or secondary air, mixes with the air jet. This process is illustrated diagramatically in Figure 9.1. The average air jet velocity decreases with distance from the nozzle but the total volume of the air jet increases and the total momentum of the air jet is preserved. The increase in volume, due to entrainment, and the decrease in jet velocity continue until a point where there is an imperceptible difference between air movement induced by the air jet and normal workplace air movement. At this point the motion of the air jet has effectively ceased. (NB: the velocity of a jet falls to ~ 1/10 of its initial velocity at ~ 60D distance. This rule-of-thumb distance is often, incorrectly, quoted as 30D).

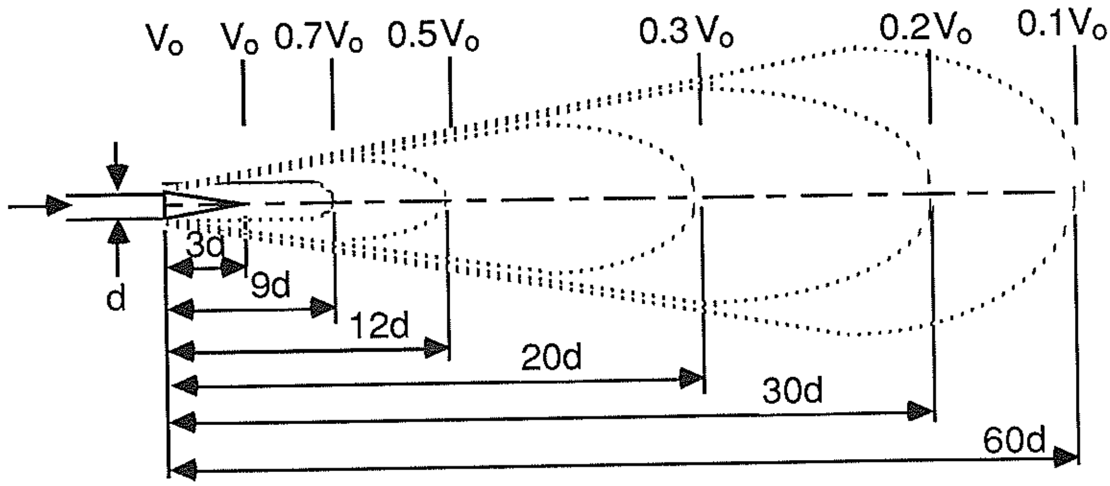

Figure 9.1
Centreline velocities in a jet with approximate velocity contours superimposed.

The rate of decrease in jet velocity, its expansion and degree of entrainment are predictable. Thus, for instance the CIBS (1977) provide one simple formula for predicting the velocity of air movement at distances from the jet nozzle greater than about 8 times its diameter, which is reproduced below.

$$X = \frac{KQ}{V_x (A_f C_d)^{1/2}}$$

where

X = distance from nozzle
K = characteristic constant (round nozzle 7.0; standard grill 5.7 where outlet velocity is 4-8 ms^{-1})
Q = volumetric flow rate
V_x = velocity at point X
A_f = free area of discharge
C_d = coefficient of discharge (well rounded nozzle 1.0; sharp edged orifice 0.6)

The centreline velocities derived from this formula are shown in Figure 9.1. (The velocities are calculated assuming a well rounded jet nozzle where K = 7.0 and C_d = 1.0. With these assumptions the equation can be rearranged to produce the simplified form $n = 6.2 \times V_o/V_x$ where n = distance X in terms of the number of jet nozzle diameters; V_o = initial jet velocity; V_x = jet velocity at distance X. In this form the equation conforms to that given by BENDER (1979) for "point sources" in the Appendix to Chapter 7).

HEMEON (1963), BENDER (1979), BATURIN (1972) and CROOME-GALE and ROBERTS (1975) also provide equations for predicting the characteristics of air jets (the latter authors for non-isothermal jets) and the reader is advised to use the different equations to predict the likely range of values for the parameter of interest (velocity, entrainment ratio, volume). Such calculations can then be used as first approximations in the design process.

9.10.2 The Uses of Air Jets

Air jets can be used as part of the general ventilation of a workplace to encourage the mixing and dispersion of contaminants. They can be divided into two types:

(1) Air jets which are created within the workplace using recycled workplace air.

(2) Air jets which draw air from outside the workplace.

In the first case the jet air is used to ensure even mixing of contaminant with fresh diluting air, introduced by the general ventilation system. This may be necessary where either the contaminant is physically confined (eg styrene vapour within the hull of a glass reinforced plastic (GRP boat)) or is produced close to the worker's breathing zone (eg during welding). A "man cooler" or other air ejector device can be very successful in preventing the local build up of relatively high concentrations of contaminant (see for instance ALESBURY 1980). However, such air jets do not supply fresh air to the area they cover. Also, because they cause more effective dispersion of the contaminant, while they reduce the problem for those people whose exposures would have been high they may well increase, by a small but significant amount, the exposure of others in the workroom.

In the second case, primary air used to create the air jet is drawn from outside the building, and the jet can in fact be created as part of the ventilation air replacement system. Because "fresh air" is used such jets can potentially provide cleaner spot ventilated environments than recirculating air jets. However whether this is the case in practice will depend upon how far the jet travels before arriving in an area where people work. If it has travelled a relatively large distance (compared with the width of the jet nozzle) through contaminated air, entrainment will ensure that the jet air is contaminated. If such jets are carefully sited they can be used to provide relatively clean local environments. Their use, as part of a general ventilation system, is to be encouraged.

9.10.3 Air Curtains

Air jets can be used as "air curtains" to reduce the exchange of air across an opening. Their most common use is to reduce the flow of cold air into a heated building. The same principle could be applied to reduce the spread of a contaminant. However, in many potential applications, there is a distinct chance that the air curtain will interact with the contaminated air and may, rather than confine the contaminant, actually aid its dispersion. In the majority of cases where air curtains could be used to segregate a process, which is fixed or mobile within a strictly defined space, the use of solid enclosing walls is preferable and more reliable. Having made this proviso there are circumstances where the contaminant generating process is mobile and the work environment is unpredictable, where air curtains can be and have been used to restrain the movement of contaminated air. One successful application of air curtains in coal mining is described by FORD and HOLE (1984).

9.10.4 Air Douches

These are specialised versions of fresh air jets, but rather than the air issuing from a narrow nozzle at a relatively high velocity at a distance from the worker, air is discharged from a wide nozzle or plenum at relatively low velocity close to the worker. The designer usually aims to ensure that there is minimal entrainment and mixing of secondary contaminated air with the clean primary tempered air by the time the air jet has reached the breathing zone of the worker (see Figure 9.2). Air douches can be applied close to where people work because the air jet produced, although wide, does not move at high velocity and is not unpleasantly draughty, unlike a fresh air jet applied close to the nozzle. BATURIN (1972) provides useful information on the design of air douches and cites examples of their successful application in a steel works (for carbon monoxide control) and a leather works where formaldehyde was a problem. More recently FORD and HOLE (1984) have described the successful application of a canopy air douche system above the head of the operator on a mobile heading machine in a coal mine. The initial canopy design (41 x 41 cm approx) provided ~ 70% protection against respirable dust using 0.24 m^3s^{-1} of air recirculated through an intake filter of 85% efficiency. However, the "protected zone" was little larger than the workers head and the air douche was deflected at air speeds greater than 1.5 ms^{-1}. A larger canopy, with an integral air curtain of novel design, increased the volume of the "protected zone" which remained stable at external air velocities of greater than 1.5 ms^{-1}. However the reduction of exposure was limited (~ 20% for the initial canopy design) because the machine operator only spent 1/3 of the shift beneath the canopy. This example illustrates that air douche systems will only work efficiently if:

1 They cover the area where work people spend most of their time.

2 Workplace draughts are deflected or suppressed.

3 The primary air is clean (in the example quoted the effectiveness of the canopy was limited by the efficiency of the recirculating air filter) and its temperature is controlled.

There are examples of the successful application of air douches in the control of exposure to lead dust in battery manufacture (see BULLOCK, 1985) and potentially in coal mines, however at present they are not greatly used in manufacturing industry. Where people work in defined areas of a workplace and are exposed to contaminant from large sources or many small sources, which are not amenable to LEV control, the effectiveness of general ventilation applied to control exposure could be greatly enhanced by air douches.

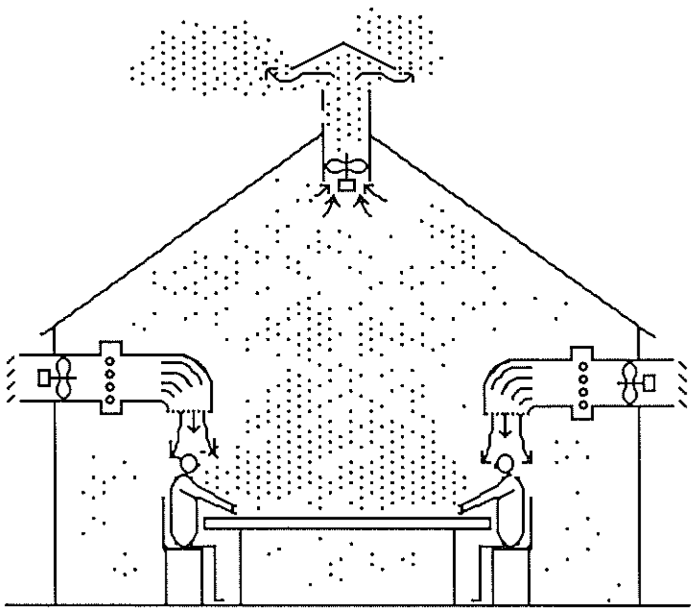

Figure 9.2
Air douches
Workers breathe fresh tempered incoming air.

9.10.5 Problems with Air Jets

The use of free air jets in contaminant control should be approached carefully. Various untoward effects can occur including

1 Widespread and unwanted dispersion of contaminant (mentioned already in 9.10.2).

2 Disruption of existing LEV applied to process. Captor hoods (see Chapter 8.0) are particularly susceptible to draughts.

3 Operators may find the air flow draughty and cold, though this is less likely with the low velocity air douche provided that the primary air is tempered.

4 Free air jets (excluding air douches) may induce large scale vortices in which contaminant may become concentrated (LJUNGQVIST, 1979), or, in work environments where contaminants collect in the roof space, induced vortices may recirculate contaminated air from the roof space down to ground level where people work. A knowledge of existing air movement within the work room should allow the designer to predict the effect of an air jet, at least qualitatively. In the case of large projects or costly schemes it may well be worth investigating the proposed design by means of a hydraulic model (CURD, 1984).

In summary then, air jets can greatly enhance the effectiveness of general ventilation and their use is to be encouraged. However, they should not be installed without careful thought as to how they will interact with the contaminating process, any LEV present, and how they might change large scale work room air movement for the worse.

9.11 Ventilation of Enclosed Spaces

Certain repair and demolition jobs have to be performed in enclosed spaces where the dilution effect of any general ventilation is severely reduced. Unlike confined spaces in enclosed spaces there is sufficient exchange of air with the general environment so that oxygen deficiency is unlikely to be a problem. However toxic concentrations of air contaminants can easily develop unless the enclosed space is properly ventilated.

Perhaps the first criterion for ventilation of enclosed spaces was that of TEBBENS and DRINKER (1941) who recommended minimum ventilation rates of 0.1 - 0.3 m^3s^{-1} per welder (depending on rod diameter) when welding mild steel plate, and 0.7 m^3s^{-1} on galvanised plate. Later, the US Department of the Navy (1949) specified minimum air change rates in confined spaces in the range 0.25-1.0 per minute.

More definitive studies were published by BRIEF et al (1966) on exposure to fume during welding inside petroleum process vessels. They found that general ventilation by upflow exhaust was the most effective form of ventilation control during overhead welding (Figure 9.3a), and that downflow was most effective for downhand work (Figure 9.3b). They also found that dilution of fumes by an airflow of about 0.5 ms^{-1} over the work area was effective if combined with general ventilation (Figure 9.3c), and that local extract (Figure 9.3d), whilst effective, was of limited practicability.

They developed a formula to calculate the necessary general ventilation rate which in SI units is:

$$Q/A = 0.236 \log (C_i/C)$$

where

C_i = concentration without ventilation
C = concentration required with ventilation
Q/A = average air velocity in tower, ms^{-1}
Q = volumetric airflow, m^3s^{-1}
A = cross sectional area of tower, m^2

It was observed that efficient ventilation was often lost by failure to seal the air mover to the flanged opening on the vessel.

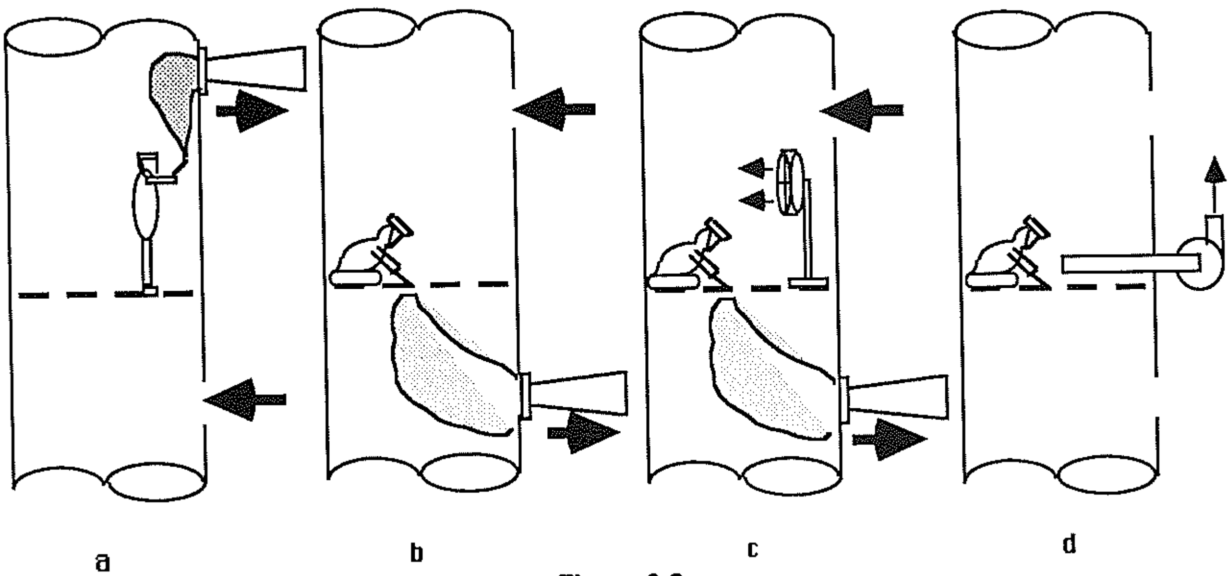

Figure 9.3
Ventilation for welding in an enclosed space (see text).

General Ventilation

Where there is minimal exchange of air with the general environment oxygen deficient atmospheres are likely to exist and toxic concentrations of contaminants may be present or develop rapidly. Work in confined spaces should be treated differently from work in enclosed spaces.

9.12 Ventilation of Confined Spaces

Many serious accidents occur while work is being done in confined spaces such as tanks, underground chambers, pits and flues. A recent study, HSE (1985) reported that, over the 3-year period 1980-82, 19 people were killed by gassing or asphyxiation in confined spaces. In many of these cases, little or no ventilation was provided, typically resulting in hazardous vapour concentrations of the order of 1% or depletion of the oxygen content to less than 15%. In factories and other premises covered by the Factories Act 1961, there are statutory requirements covering conditions for entry to confined spaces which should also be followed in premises covered by the HASAWA. These requirements relate to the minimum size of access openings, the use where necessary of suitable breathing apparatus, atmospheric testing, the need for adequate supervision and arrangements for rescue. Further information on entry to confined spaces may be found in HSE (1980).

Wherever work is to be undertaken in a confined space, a thorough assessment of the atmospheric conditions inside the space should be made, and no one should be allowed to enter unless either he is fully protected by suitable breathing apparatus or the atmosphere has been certified as safe for entry without breathing apparatus. In the latter case it will be necessary to check that there is no source of gas or fume within the confined space and that adequate ventilation is provided to maintain an atmosphere that is safe be breathe.

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10

VENTILATION HARDWARE AND SYSTEM DESIGN

The term ventilation hardware refers to:

(a) ductwork and associated bends, fittings, changes of cross-section
(b) fans and air movers
(c) air cleaners (filters, cyclones etc)
(d) discharges to outside

The costs of ventilation hardware are considered in section 6.2.

10.1 Ductwork

This consists of straight ducts, bends, changes of cross-section, dampers and other fittings needed to connect the suction inlet to the point of discharge and incorporating other hardware (fans etc) all designed so that the system can be accommodated in the building in which the workplace is housed. The cross-sectional shape of the ducts is normally either circular or rectangular.

10.1.1 Duct Sizing

The volume flow rate of air will already be determined by the requirement of the suction inlet or discharge. The relationship between volume flow rate (Q) and cross-sectional area (A) at any point in the system is given by the expression:

$$Q = VA$$

where V is the air velocity. If Q is in m^3s^{-1} and A in m^2, V will be in m s^{-1}. Therefore cross-sectional area of the duct will be determined by either the air velocity that is required or by the space that is available to site the duct. It should be remembered that system pressure loss is proportional to V^2 thus, for a given volume flow rate, a large cross-sectional area duct will result in a low air velocity and low energy losses but will use more materials of construction than one of a small cross-sectional area. The smaller cross-section will result in higher air velocities and high friction energy losses and will generate more noise.

Where particles of powder or dust are to be carried it is essential to maintain a sufficient air velocity within the duct to ensure that deposition does not occur within any part of the ductwork system; thus the air velocity is determined by the need to maintain what is known as the Transport Velocity. A range of transport velocities is given in the Table 10.1.

Table 10.1
Recommended transport velocities

Pollutant	Transport velocity (ms^{-1})
Fumes, such as zinc and aluminium	7 - 10
Fine dust, such as lint, cotton fly, flour, fine powders	10 - 12.5
Dust and powders with low moisture content, such as cotton dust, jute lint, fine wood shavings, fine rubber dust, plastic dusts.	12.5 - 17.5
Normal industrial dust, such as sawdust, grinding dust, food powders, rock dusts, asbestos fibres, silica flour, pottery clay dust, brick and cement dust.	17.5 - 20
Heavy and moist dust, such as lead chippings, moist cement, quick-lime dust, paint spray particles.	Over 22

If only gases and vapours are to be carried, then transport velocities are not important and the air velocity becomes a matter of economics or acoustics. Optimum velocities are usually between 5 and 6 m s^{-1} but if noise levels are not to be obtrusive, 5 m s^{-1} should be the maximum.

A circular cross-section is more economical in material than a rectangular one but, in some buildings, the space available into which the duct can be placed is more suited to a rectangular shape, eg in false ceilings.

10.1.2 Pressure Losses

In order to choose the correct fan to overcome the airflow resistance of the ducts and fitting it is necessary to sum the pressure losses created by each item throughout the system. In the SI system of units, pressure losses are expressed in the unit pascal (Pa), where 1 Pa equals 1 Nm^{-2} . There are various calculation techniques available, the two most common being:

1 The method favoured by the CIBS in the United Kingdom (CIBS, 1977) and illustrated below.

2 The method favoured in the USA by ACGIH (ACGIH, 1984).

The basic difference is that the UK method treats the straight ducts separately from the bends and fittings and involves calculations for each individual fitting, whereas in the USA method the bends and fittings are treated as having a pressure loss corresponding to an equivalent length of straight duct.

When designing a system it is useful to draw a sketch of the layout identifying each junction where the air changes speed or direction or where two airstreams meet, by assigning the change point with a number. A table should be drawn up with headings as shown in Table 10.7.

The Table should be filled in section by section starting from the inlet farthest from the fan using the design information selected as appropriate to the requirements of each section. It is not necessary to complete every column for each section as they do not always apply and it may be necessary to leave some sections until after the succeeding section has been designed. The last column to the right of the table is the sum of the pressure losses accumulated from the beginning and this provides a statement of the pressure inside the duct at the point in relation to atmosphere and is a useful piece of information to use when checking the system after installation.

The values given in the charts and tables below are for ducts made of galvanised sheet steel. If the ducts are made of any other material such as brick, concrete, plastic, GRP etc the calculation proceeds as if for sheet steel but the final pressure loss is multiplied by a factor for the material used. Such factors are given in CIBS (1977).

10.1.4 Straight Ducts

Pressure losses in straight ducts of circular cross-section can be obtained from the chart in Figure 10.1, knowing the volume flow rate and the duct diameter.

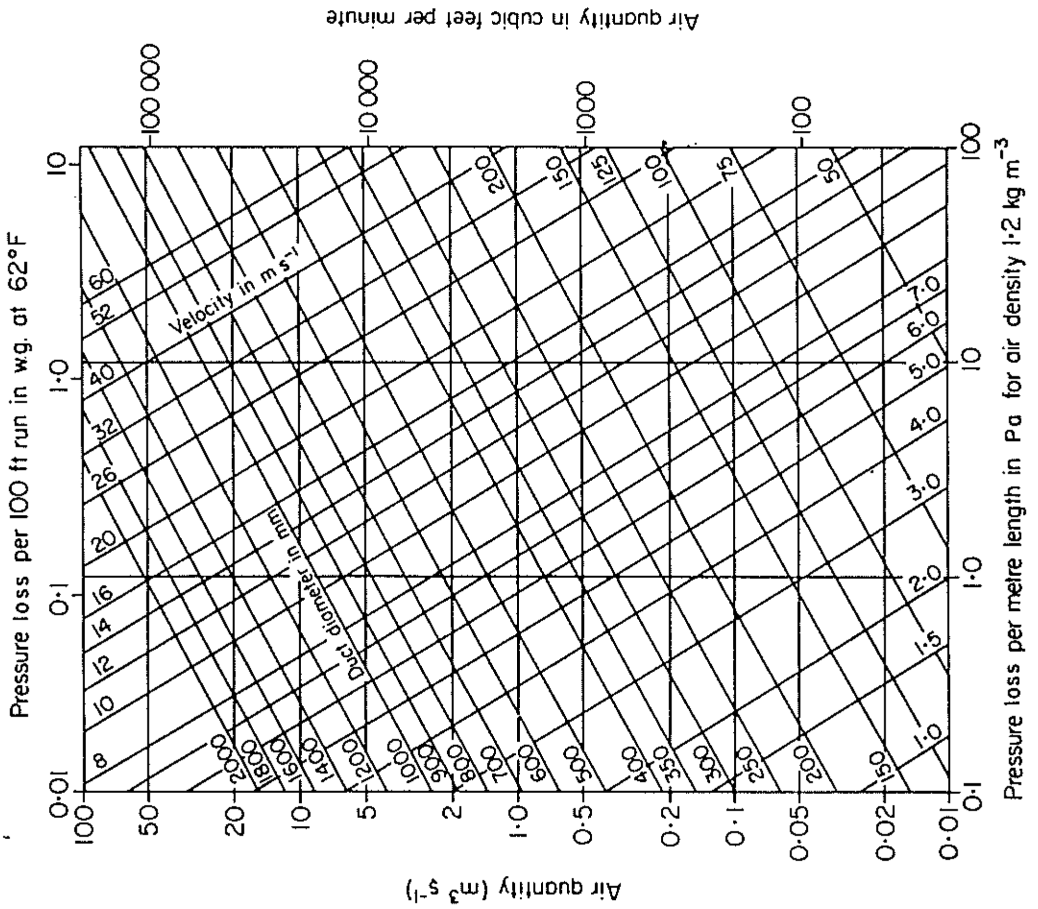


Figure 10.1
Duct sizing chart for straight ducts made of galvanised sheet steel.

For rectangular ducts the chart in Figure 10.1 can be used if an equivalent diameter is calculated. Equivalent diameter (d) is the diameter of a hypothetical circular duct which has the same friction loss as the rectangular duct when carrying the same volume flow rate and is calculated from the expression:

$$d = 1.265 \frac{\left[(ab)^3\right]^{0.2}}{a+b}$$

where a and b are the dimensions of the sides of the rectangular duct.

10.2 Fittings

In order to estimate the total pressure loss in fittings it is necessary to make use of the velocity pressure at a point in the fitting. Velocity pressure (P_v) is calculated from the expression:

$$P_v = \rho \frac{V^2}{2}$$

If the air density (ρ) is in kg m^{-3}, the air velocity (v) is m s^{-1} then P_v is in Pa. Standard air at 20^{o}C and 1013.25 mb (barometric pressure) has a density of 1.2 kg m^{-3}, therefore this expression becomes:

$$P_v = 0.6V^2$$

which can be used for most room temperature applications in the United Kingdom.

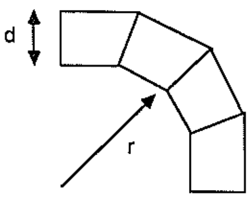
10.2.1 Bends

Pressure losses in bends (ΔP_b) can be calculated from:

$$\Delta P_b = kP_v$$

The value of k for circular ducts depends upon the ratio of the inside bend radius to the duct diameter (r/d) and the number of sections that make up the bend as given in the table below.

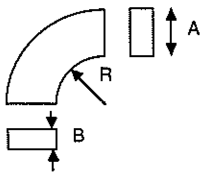
Table 10.2
Pressure loss factors for bends in circular ducts.



Number of sections	Radius ratio r/d					
	0.5	0.75	1.0	1.5	2.0	2.5
Plain radius	0.26	0.21	0.18	0.16	0.14	0.15
4	0.41	0.36	0.32	0.26	0.22	0.21
3	0.45	0.38	0.35	0.32	0.32	0.34
2	1.2					

The value of k for rectangular ducts depends upon the aspect ratio of the sides of the duct B/A and the ratio of the inside bend radius to the dimension of the side (R/A), as shown in Table 10.3.

Table 10.3
Pressure loss factors for bends in rectangular ducts.

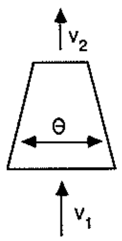


B/A	R/A 0.25	0.5	0.75	1.0	1.25	1.5
0.2	0.65	0.46	0.42	0.40	0.40	0.41
0.3	0.58	0.38	0.37	0.36	0.36	0.36
0.5	0.50	0.28	0.22	0.21	0.21	0.21
1.0	0.45	0.25	0.19	0.16	0.16	0.15
2.0	0.35	0.20	0.15	0.12	0.12	0.12

10.2.2 Changes of Section - Conical Contractions

Pressure loss, $\Delta P_c = k P_{v_2}$ where v_2 refers to outlet velocity and k is given in Table 10.4.

Table 10.4
Pressure loss factors in contractions.



θ	K
30	0.02
45	0.04
60	0.07

10.2.3 Expanders

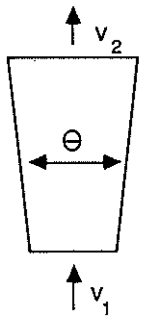
Pressure loss ΔP_e is calculated from:

$$\Delta P_e = k(Pv_1 - Pv_2)$$

where Pv_1 and Pv_2 are the velocity pressures corresponding to the inlet velocity (v_1) and the outlet velocity (v_2) respectively.

The factor k is dependent upon the angle of expansion and the ratio of velocities v_1/v_2 and values are given in Tables 10.5 and 10.6 for rectangular and conical expanders.

Table 10.5
Pressure loss factors for expanders in rectangular ducts.



Rectangular						
v_2/v_1	θ = 5	10	15	20	25	30
0.2	0.11	0.18	0.39	0.54	0.64	0.70
0.3	0.09	0.15	0.31	0.43	0.51	0.57
0.4	0.07	0.12	0.25	0.34	0.41	0.45
0.5	0.05	0.09	0.19	0.26	0.31	0.35
0.6	0.04	0.07	0.15	0.20	0.24	0.26
0.7	0.03	0.05	0.10	0.14	0.17	0.19

Table 10.6
Pressure loss factors for expanders in circular ducts.

Conical								
v_2/v_1	θ = 5	10	15	20	25	30	35	40
0.2	0.09	0.11	0.18	0.27	0.40	0.54	0.63	0.68
0.3	0.07	0.09	0.14	0.22	0.32	0.43	0.51	0.55
0.4	0.06	0.07	0.11	0.17	0.25	0.34	0.41	0.44
0.5	0.05	0.05	0.09	0.13	0.20	0.26	0.31	0.34
0.6	0.03	0.04	0.07	0.10	0.15	0.20	0.24	0.26
0.7	0.02	0.03	0.05	0.07	0.11	0.14	0.17	0.18

Table 10.6
Pressure loss factors for expanders in circular ducts

10.2.4 Other Fittings

The pressure loss within hoods, slots and enclosures must be included in the sum of total pressure losses. This value will depend upon the shape and configuration of the device but some guidance can be found in ACGIH (1984) and HARRINGTON and GILL (1983).

Filters and air cleaners pose a problem in that, with the exception of certain types of air cleaners, the pressure drop across a filter increases as the dust loading increases. The range of filter pressures to be included in any total loss calculation can be obtained from the manufacturer.

Grilles and louvres create a pressure loss which if they are commercially supplied can be obtained from the manufacturer but if "home made" some estimate of loss can be found (CIBS,1977 and DALY, 1978).

10.3 Multi-Branched Systems

It is not unusual with extract systems to join together several branches, all feeding to a single duct and fan. When this occurs, the pressure required to specify the fan is normally taken as that required to bring the air from the inlet farthest from the fan, the "index" inlet, through the system to the discharge point. Sufficient pressure will be available to overcome the resistance of the intermediate branches, ie those nearer the fan. In fact there may be an excess of pressure making it necessary to restrict the intermediate branches in order to prevent an excessive airflow from passing through them to the detriment of the farthest branch. This results in the multi-branched system being out of balance, a common fault with many industrial systems which have been in use for some time. Balancing can be achieved by installing adjustable dampers in the intermediate branches or by making those branches higher in resistance by design. The damper method has the disadvantage of being thrown out of balance by injudicious tampering unless the damper handles are locked in the balanced position. Also, if dust is to be carried in the duct the dampers can act as a depository, such that unwanted accumulations of dust can build up, making the damper unworkable and causing an unnecessary obstruction in the duct. Inherent balancing by design is, therefore, to be preferred.

10.4 System Design

Should a multi-branched system become unbalanced due to altered damper positions, an organised method of balancing must be adopted such as the one advocated in the CIBS Code of Practice (CIBS, 1977).

An example is given here, taken from GILL (1980). For the purpose of this example, ducting of circular cross-section is used on the suction side of the fan (centrifugal type) but rectangular cross-section is used on the discharge side, the material being galvanised sheet steel.

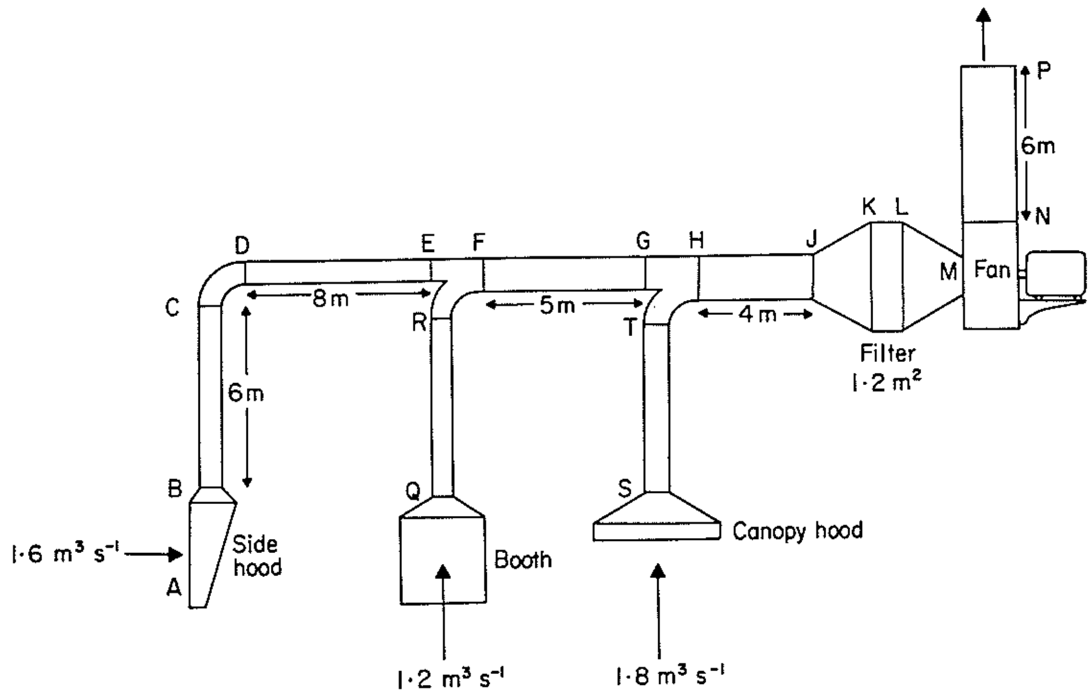


Figure 10.2
Schematic diagram of ventilation system used as an example in Table 10.7.

Note: the point A represents room or atmospheric pressure; this appears at the beginning of each branch and at the end of the system.

The diagram shows a typical three-branched extract system each branch having a different type of suction inlet: a side hood, a booth and a canopy hood. The airflow rates have been chosen arbitrarily but are not untypical.

Table 10.7
Specimen duct sizing example based on Figure 10.2.

Section	Length (m)	Volume flow rate ($m^3 s^{-1}$)	Duct dimension (mm)	Duct area (m^2)	Air velocity ($m s^{-1}$)	Velocity pressure ($N m^{-2}$ (Pa))	Pressure loss factor k	Pressure loss per unit length ($N m^{-2}$ per m)	Section pressure loss ($N m^{-2}$ (Pa))	Cumulative pressure loss ($N m^{-2}$ (Pa))	Remarks
A–B		1.6	diam. 370	0.107	15	135	0.25		34	34	Hood
B–C	6	1.6	diam. 370	0.107	15	135		6.5	39	73	
C–D		1.6	diam. 370	0.107	15	135	0.42		57	130	Bend
D–E	8	1.6	diam. 370	0.107	15	135		6.5	52	182	
E–F		1.6	diam. 370	0.107	15	135	0.40		54	236	Junction (through)
F–G	5	2.8	diam. 490	0.187	15	135		4.6	23	259	
G–H		2.8	diam. 490	0.187	15	135	0.4		54	313	Junction (through)
H–J	4	4.6	diam. 625	0.310	15	135		3.3	13	326	
J–K		4.6	angle 60°		ratio 0.21	diff. 129	0.67		87	413	Transformation enlargement round to square
K–L		4.6	1.2 m sq.	1.44	face 3.2	6			420	833	Filter (manufacturers data)
L–M		4.6	angle 60°		3.2–20	240	0.07		17	850	Transformation contraction square to round
M–N	Fan		inlet diam. 540	0.23	20	240			fan total pressure		
N–P	6	4.6	600 × 500	0.30	15.3	141		4.0	24	24	Rectangular fan discharge stack
P–A		4.6				141			141	165	Discharge velocity

Total pressure required on suction side of fan = 850 $N m^{-2}$ and on discharge side = 165 $N m^{-2}$, therefore fan total pressure required = 850 + 165 = 1015 $N m^{-2}$. Note that point A represents atmospheric pressure, i.e. anywhere in the room or outside. Note also that it will be necessary to size the straight lengths of duct first before details of the fittings can be designed thus sections of the system have to be passed over and returned to later.

A duct air velocity of 15 ms^{-1} has been chosen and it is assumed that the air is at standard density. The solution is given in Table 10.7.

Having worked through the table section by section from one extreme end to the other*, it is necessary to examine the intermediate branches. It can be seen from the table that the cumulative pressure at point F is 236 Pa, therefore the pressure loss through branch AQRF must be the same, and yet the distance is shorter and the branch happens to be carrying less air than ABCDEF. Likewise, the cumulative pressure at point H is 313 Pa therefore branch ASTH must have that pressure loss. If no steps are taken to allow for this, and similar duct sizes are chosen as in the index branch, then, when the system is installed and the fan turned on, the bulk of the airflow will pass through the branch nearest the fan and very little through the one farthest away, thus the system is out of balance.

In order to size the intermediate branches to balance the pressure losses correctly, equations can be derived which will produce a mathematical solution but it is probably as quick to solve the problem by an iterative "trial and error" method, ie choose a duct slightly smaller than in the index branch and work through the pressure loss calculations. If the pressure loss is too small, choose a yet smaller duct; if too large, choose again a larger duct and repeat until the correct duct size is deduced.

In the example, fan manufacturer's catalogues should be consulted to find a suitable fan to provide the duty of 4.6 m^3s^{-1} at a total pressure of 1015 Pa*.

10.5 Fans

In order to establish the duty of a fan to draw air through the sytem, it is necessary to sum the individual pressure losses from each of the components, starting from the suction inlet and working towards the fan. If there are components on the delivery side of the fan, then it is also necessary to add the pressure losses on that side.

* Fan total pressure is inlet side pressure loss plus outlet side pressure loss

At the Reynolds numbers found in most components of an extract system, the pressure loss is proportional to the square of the volume flow rate. Thus, once the pressure loss is calculated for a particular volume flow rate, losses for all other flows can be simply calculated. It follows that the system can be represented by a curve plotted on linear coordinates of the form y proportional to x^2 (ie a parabola), passing through the origin and the calculated duty point. It is normal to plot pressure on the y-axis and volume flow rate on the x-axis and, from this curve, the pressure loss for any other flow can be read. This curve is known as the System Resistance Characteristic and is shown in Figure 10.3.

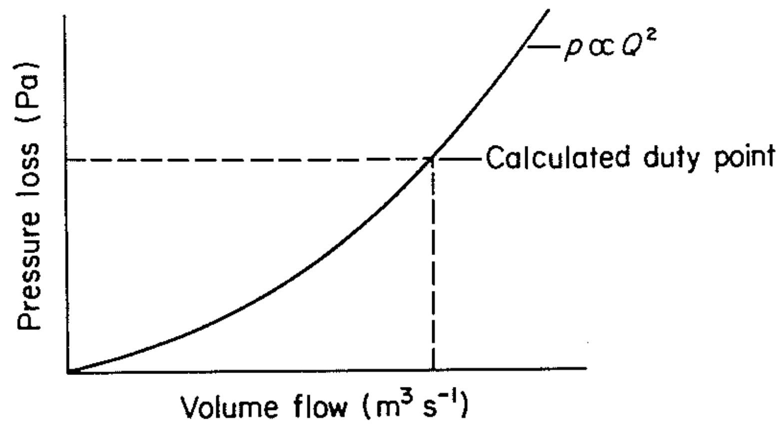


Figure 10.3
System resistance characteristic.

10.5.1 Choice of Fan

Fan Pressure

The Fan Manufacturers' Association has agreed the following definitions for the various fan pressures:

Fan total pressure: the rise in total pressure across the fan which is equal to the algebraic sum of total pressure at the fan outlet minus the total pressure at the inlet.

Fan velocity pressure: the velocity pressure based on the mean velocity at the fan outlet.

Fan static pressure: the fan total pressure minus the fan velocity pressure.

10.5.2 Power and Efficiency Definitions

Air power (total): the theoretical power required for a volume of air to move at a given rate against a resistance and is calculated from:

$$P_a = QP_t$$

where P_a is the air power (total)
Q is the volume flow rate.
P_t is the total pressure required to move that flow rate.
If Q is in m s^{-3} and P_t in P_a or pascal, then the resulting power will be in watts.

---

* In most cases the system extracts from points at atmospheric pressure and discharges also to atmospheric pressure.

Fan efficiency (total): the ratio of the air power total to the input power at the shaft of the fan impeller.

Fan power (total): the power required at the shaft of the fan impeller to move the air against the resistance. It is calculated from:

$$P_t = \frac{Q \times P_t}{\eta}$$

where P_t is fan power (total) and η is fan efficiency (total).

10.5.3 Fan Characteristic Curves

If a fan is run at a constant speed and its volume flow rate altered by varying the resistance against which it has to operate, curves showing the variation of pressure, power and efficiency can be plotted against volume flow rate. These curves, known as fan characteristic curves, give the performance of the fan over the whole range of resistance for which it is designed. Manufacturers' catalogues quote these curves either as graphs or as tables. The shape of the curve depends upon the geometric shape of the fan. Typical curves are shown in Figure 10.4.

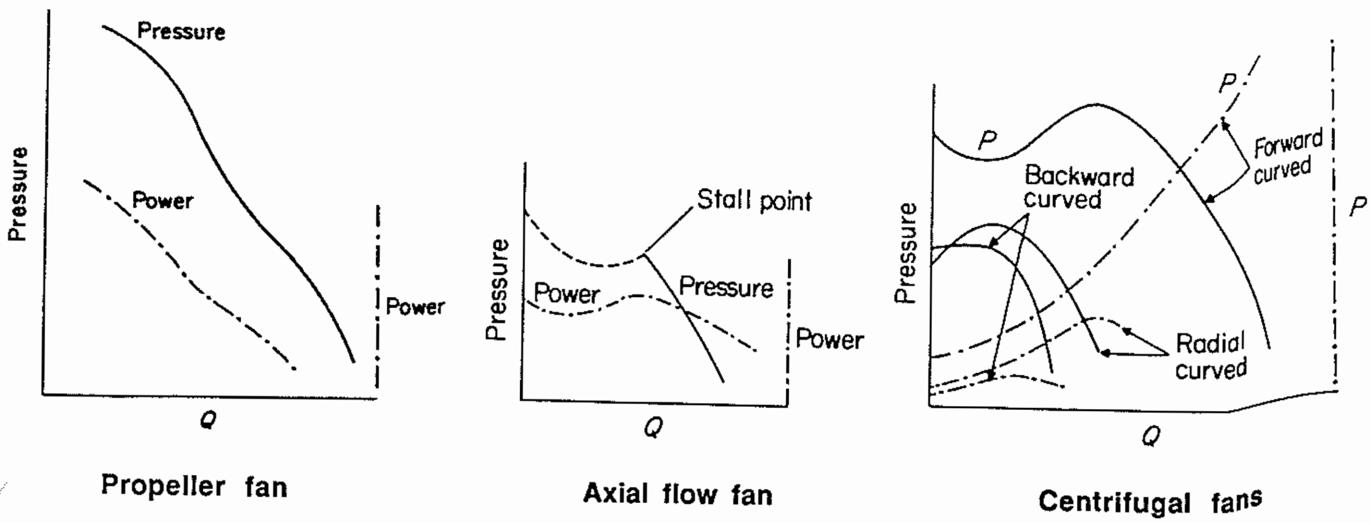


Figure 10.4
Fan pressure and power characteristics.

10.5.4 Matching of the Fan and System

Where the fan curve intersects the system curve the duty point will occur and the appropriate pressure and power can be read from the curves, see Figure 10.5.

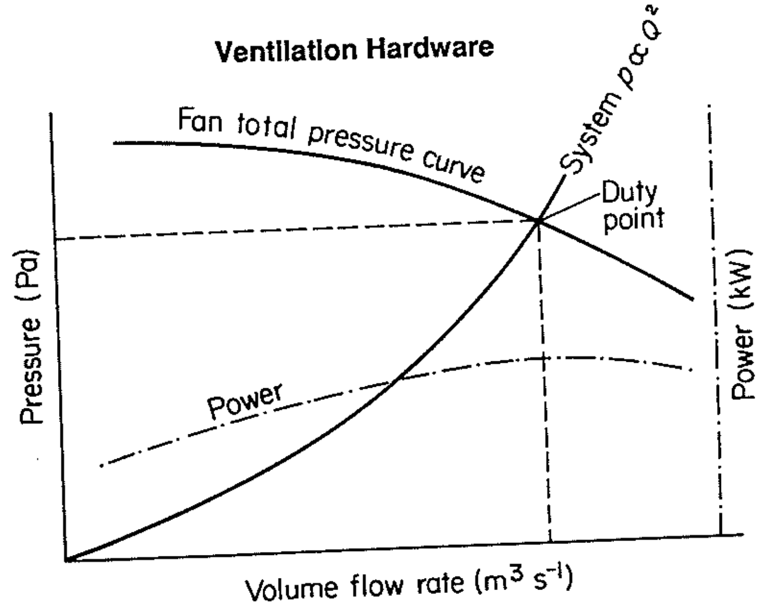


Figure 10.5
Interaction between the system and the fan characteristic curves.

10.5.5 Fan Types

This section describes the commoner types of fan used in ventilation systems. Sketches showing their salient features plus characteristic curves are given. In the curve p represents pressure, P power and Q volume flow rate.

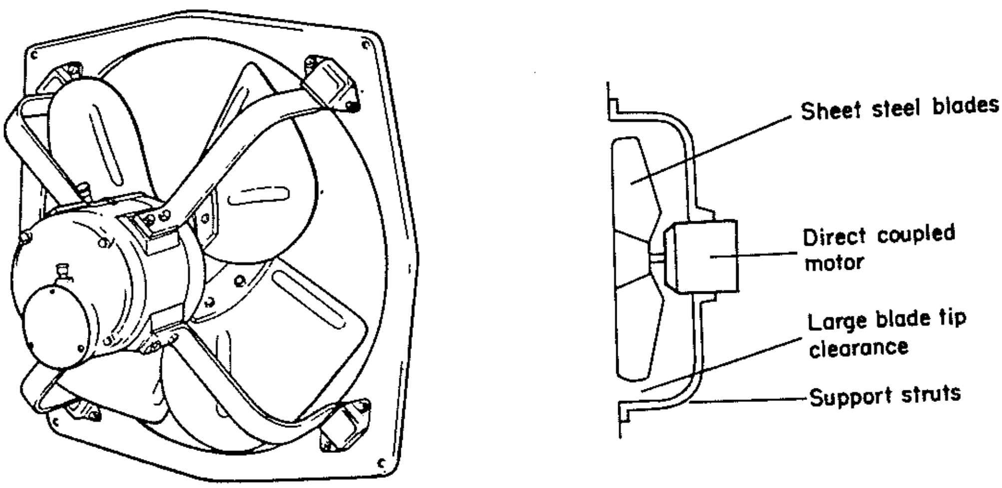


Figure 10.6
Propeller fan.

In the propeller fan the blades are usually sheet steel rivetted to a hub which is directly attached to the shaft of an electric motor. Fans of this type are not capable of producing very much pressure and work best when operating against a low resistance to airflow. Therefore they are normally used for general space ventilation when no ducts are involved. They are also commonly found on refrigerator condensers. Some propeller fans have aerofoil shaped blades for higher efficiency and are used on cooling towers and higher flow rate applications; however such fans could be regarded as short cased axial flow fans.

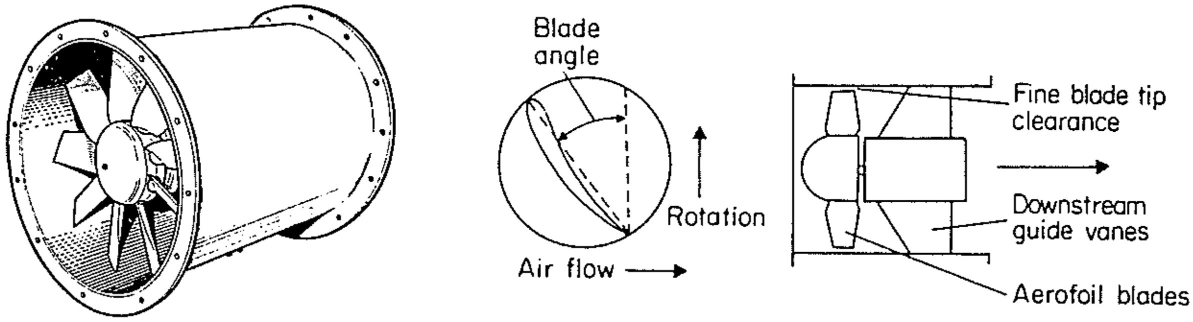


Figure 10.7
Axial flow fan details.

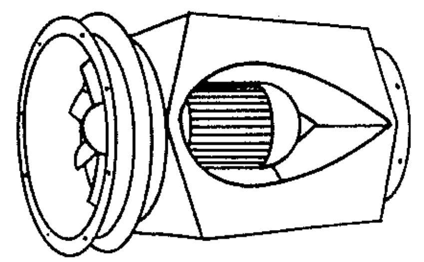


Figure 10.8
A bifurcated axial flow fan.

Axial flow fans have an impeller with blades of aerofoil section rotating inside a cylindrical casing with the air entering and leaving the fan in the same direction. With the smaller fan the impeller is usually directly coupled to the electric motor thus the motor will be in the air stream. This may be a disadvantage if the air is hot or laden with dirty or corrosive material. A bifucated axial flow fan is designed to protect the motor from such an atmosphere.

The air leaves the impeller with a rotary motion which requires to be corrected in order to recover some of the energy of rotation. This can be achieved by placing static vanes up stream or down stream of the impeller to provide opposite pre-rotation if up stream or to remove rotation of downstream.

Guide vanes are not necessary if the fan blows air into a device which acts as a flow straighter such as a finned tube heater battery or a bifurcation. Axial fans are limited in the pressure they develop and may have to be staged if high pressures are required although often it is cheaper to install a centrifugal fan than a two stage axial flow fan. The great advantage of the axial fan is its compactness, being capable of attachment to circular ducting of the same diameter and producing more volume flow rate than a centrifugal fan of the same size. However, they tend to be noisy and can go into stall condition if asked to work against high resistance ventilation systems. Performance variations can be achieved by blade angle changes or speed changes if these facilities are built into their design.

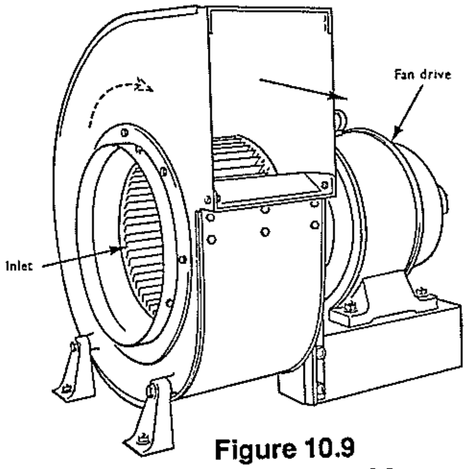


Figure 10.9
Typical centrifugal fan.

The centrifugal fan has an impeller rotating inside a casing shaped like a scroll. The impeller, which looks something like a paddle wheel, draws air into the centre and throws it out at the periphery. The casing gathers the air which has a high velocity pressure and converts it into static pressure, therefore the air leaves the fan at right angles to the direction in which it enters.

Differences in performance and efficiency are achieved by having impellers of various shapes depending upon the angle of the blades in relation to the direction of rotation, ie forward, backward and radial blade. These are illustrated in Figure 10.10.

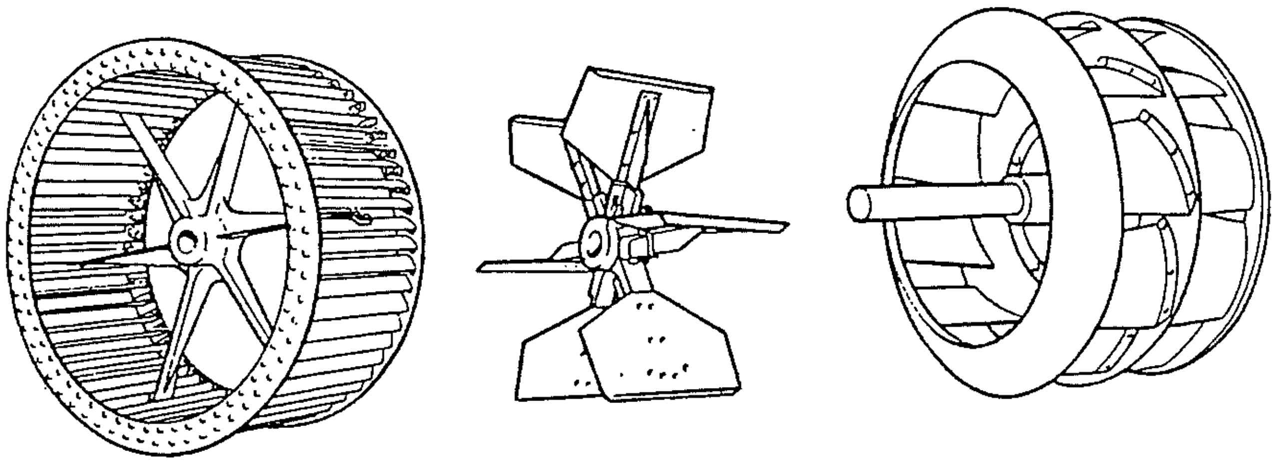


Figure 10.10
Forward, radial and backward bladed impellers.

The forward bladed impeller can handle more air than for a given diameter the other types but has the disadvantage of having an overloading power characteristic, ie it requires a high power when acting against a low resistance.

The radial impeller is normally found in the paddle bladed form which has a low efficiency but the advantage that the blades have a self cleaning action making it suitable for handling dirty air. Also worn or corroded blades are easier to replace than with the other forms of centrifugal fan.

The backward bladed is normally the largest of all the fans for a given duty but is the most efficient up to 90% at peak efficiency. It is normally used for heavy duty continuously running operations where saving in power costs is important.

Centrifugal fans can produce very high pressures and are best suited to operating on systems of relatively high resistance.

10.6 Air Cleaning

If particulates are to be removed from the air, both of which are dry, then dry dust collectors of various types are available. The larger particles can be removed by dry centrifugal methods as employed in cyclones, whilst bag filters will remove the smaller dusts. Particles that can be easily electrically charged can be collected by electrostatic collectors provided that there is no fire or explosion hazard in the air or the collected material. Dusts extracted in humid air or wet or sticky particles must be collected by some wet method such as employed in venturi scrubbers, wet centrifugals, or wet orifice collectors. Unfortunately, these devices leave the dust in a sludge which also could become a pollution problem. Air containing gases would be cleaned by adsorption or by chemical scrubbing according to the nature of the substance.

There are many excellent texts on the engineering control of atmospheric pollution which include the techniques available for removing substances from ventilation air. Therefore no details will be given here.

10.7 Designing for Ease of Maintenance

The designer needs to consider how access to duct work and air cleaners is to be gained and anticipate which parts of the system are likely to suffer the most wear or abrasion or which may become blocked and make these parts particularly accessible for inspection and maintenance. Inspection doors need to be sensibly sized and easily opened and the designer needs to think ahead and size replacable components of the system so that they can be easily handled, eg filter bags and filter frames should be of such a size and weight that they may be conveniently handled by one person. This sort of attention to detail may increase the initial cost of the equipment by a small amount. However, a system which is designed from the start for ease of maintenance is easier to inspect and repair and this should keep maintenance labour costs low. Also it should be possible to keep a well designed system close to its optimum performance relatively easily. The performance of systems which are hard to maintain usually degrades soon after commissioning and stays at a low and inadequate level. If attempts are made at repair the task is usually lengthy and frustrating. Systems which are not designed for ease of maintenance are usually not maintained and when tested are invariably found to be ineffective.

10.8 Discharges to Atmosphere

For many contaminants there will be a statutory requirement for control of discharges to atmosphere regulated by HM Industrial Air Pollution Inspectorate or other Inspectorates. Whether the air is cleaned or not it must be discharged to the atmosphere in such a way that it does not re-enter the building or any other building before it has been diluted to negligible concentrations. The best techniques involve discharging the air as high into the atmosphere as possible and at a high velocity. Devices such as cowls and weather caps hinder the upward throw of discharged air and are not recommended. Care should be taken to allow for local wind effects including the turbulence caused by adjacent buildings; any risk of "blow back" through the ductwork should be prevented.

10.9 References

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11

COMMON PROBLEMS, COMMISSIONING AND MAINTENANCE

Introduction

The ventilation systems used for control of airborne contamination vary in size and complexity from single-point self-contained extraction systems such as small welding fume control units to complex ducting systems used in large manufacturing workshops, which may serve hundreds of machines and incorporate extensive filtration plant. Whatever the size of the plant, it should perform according to a design specification drawn up to reflect the degree of control that is required, and its performance should be seen to be achieved and maintained. Unfortunately, these fundamental objectives are often not met and indeed it may sometimes come as quite a surprise to managers and maintenance staff that basic standards could or should be applied. There seems to be a real need for some fundamental information and education on these matters and this section sets out to give a basic framework for assessing both initial performance and adjustment (commissioning) and for making sure that this performance does not deteriorate to an unacceptable level (maintenance).

The proposed Control of Substances Hazardous to Health Regulations and Control of Asbestos at Work Regulations (HSE 1984a; HSE 1984b) will, if they are implemented in their present draft forms, have an influence on the commissioning and maintenance of ventilation plant as they will specifically require the provision and maintenance of appropriate measures to control personal exposures to hazardous substances. Guidance on the examination and testing of local exhaust ventilation plant is also in preparation (HSE 1985) and it is understood that further HSE guidance on design of local exhaust systems is being drafted.

11.1 Common Problems

Table 11.1 lists a variety of common problems, which can occur in the design and installation of exhaust ventilation systems, together with suitable remedies. Many of the errors in design and maintenance could be avoided if competent people were employed or trained.

Common Problems

Table 11.1
Common faults in local exhaust ventilation systems

1 FAULTS IN DESIGN
(a) Inadequate extract performance

Symptom	Cause	Remedy
Poor extraction performance, indicated by visible escape of dust, or high levels of exposure.	(i) Hood too far from source of contamination.	Relocate hood to give effective control.
	(ii) Hood does not enclose source sufficiently.	Re-design hood (eg increase size of hood around the process.
	(iii) Extract velocities too low.	Re-design for optimum capture velocity, and/ or fit flanges to hood.
	(iv) Disturbance due to high speed machinery.	Re-design as for (ii) and (iii).
Hood performance is erratic, sometimes giving good control, sometimes not.	(i) Excessive local draughts and turbulence.	Improve local environment by re-siting inlet air vents.
	(ii) Disturbances due to passage of vehicles and. people.	Re-route traffic or re-site process in quieter area.
	(iii) Disturbance due to operation nearby high speed machines.	Re-locate or screen process from high speed machine parts.

(b) General Ventilation

Symptom	Cause	Remedy
Stuffy or unpleasant atmosphere.	(i) Too little ventilation.	Increase mechanical ventilation capacity or increase size of natural air vents.
	(ii) Poor air distribution and mixing.	Ensure adequate air supply/extraction in all occupied areas. Install dilution fans.
Room temperature too high.	(i) Excessive solar heat or heat release from process.	Control of thermal environment by ventilation alone is insufficient. Attention should be given to process/ building design to reduce heat gains. Increase ventilation may provide some relief.
Room temperature too low.	(i) Inadequate heating.	Remedy will often not involve ventilation, but ventilation rate may be too high.*

* NB: Ventilation must not be reduced below the minimum rates recommended by CIBSE.

(ii) Excessive cold draughts.		Fit draught-proofing, reduce areas of air vents.* Ensure that make-up air supply is adequately heated.

2 VENTILATION HARDWARE (applies to both general ventilation and local exhaust ventilation plant).

Ventilation system does not meet design flow requirements.	(i) Fan capacity too low.	Install larger fan.
	(ii) Fan capacity adequate but system resistance too high.	Install fan with improved flow characteristics (eg centrifugal).
	(iii) Duct work too resistive (eg duct dimensions too small, bend radii too small).	Re-design ductwork.
	(iv) Excessive use of flexible ducting.	Reduce flexible ducting to minimum. If problems persist, install more powerful fan.
	(v) Dampers closed or seized in closed position.	Free and open dampers.
	(vi) Air filters too resistive.	Clean/replace filters if dirty. If problems persist or filters are clean, install filtration plant of lower resistance.
	(vii) Flow system is incorrectly balanced.	Rebalance, redesign as necessary.
	(viii) Discharge to atmosphere too resistive (eg "coolie hat" fitted).	Replace discharge terminal by one with lower resistance to flow.
	(ix) Axial fan not fitted with guide vanes.	Fit guide vanes.
Contaminant leakage from ductwork.	(i) Check that ductwork within building is under negative pressure.	Reposition fan outside workshop.
	(ii) Loose bolts in ductwork joints.	Tighten bolts, fit locking nuts if ductwork is subjected to significant vibration.
	(iii) Jointing material sealing broken.	Replace jointing.
	(iv) Transport velocity too low - dust settles out on ledges etc.	Increase flow velocity.
	(v) Ducting inadequately supported.	Replace damaged supp-orts. Increase number of supports if inadequate.
	(vi) Ducting eroded/corroded or not sufficiently robust.	Replace ducting. Ensure duct material is adequate for its purpose.

* NB: Ventilation must not be reduced below the minimum rates recommended by CIBSE.

High levels of contaminant persist in workroom.	Discharged air re-enters building.	Relocate discharge point (assessment of airflow characteristics around building).
Excessive noise from system.	(i) Fan/motor unbalanced.	Re-balance.
	(ii) No antivibration mountings/ couplings.	Fit antivibration devices (NB this may require the services of a skilled specialist).
	(iii) Fan has high noise characteristic.	Install quieter fan.
	(iv) Duct velocities too high.	Fit ducting with larger cross-section or install noise insulation/ absorbent materials.

3 INSTALLATION FAULTS

Fan runs in wrong direction	(i) Fan or ducting installed wrong way around.	Install correctly.
	(ii) 3-phase motors connected in wrong sequence.	Re-connect.
Design flow performance cannot be achieved.	(i) 2-stage fan installed with stages opposing.	Re-install correctly.
	(ii) Ductwork badly installed (eg loose joints, blocked ducts).	Clear blockages, tighten joints etc.
	(iii) System not properly balanced.	Follow standard balancing procedure.
	(iv) Keys missing on drive shafts.	Fit keys.

4 MAINTENANCE PROBLEMS

System deteriorates due to inadequate maintenance.	(i) Insufficient importance attached to maintenance (eg no effective management structure).	Set maintenance responsibility at higher level of management.
	(ii) No formal assessment procedure/planned maintenance system.	Set up effective procedures.
Extract performance slowly reduces.	(i) Fan belt drives slack.	Tighten belt tension.
	(ii) System becomes unbalanced.	Re-balance.

5 OPERATIONAL PROBLEMS

Fans noisy, bearings hot	Lack of lubrication	Institute regular lubrication schedule.
	(i) Local dampers closed.	Open dampers.
	(ii) Dampers seized in closed position.	Free and lubricate dampers.
	(iii) Dampers eroded/corroded.	Replace.
	(iv) Fan blades eroded/corroded.	Replace fan.
	(v) Filter blocked.	Clean/replace.

11.2 Competent Persons

For a local exhaust ventilation system to work effectively and reliably, it is essential that it is properly designed and installed and that it is put into operation and regularly examined by people who are competent to do so. The term "competent person" is often found in health and safety legislation in connection with the examination and testing of items of plant and machinery, and a number of sets of Regulations contain a requirement for local exhaust ventilation plant to be inspected regularly by a competent person. Details of these statutory requirements are given in Table 11.2. However, there has never been a comprehensive practical definition of the term "competent person" and, although the matter has occasionally been considered by the courts, no detailed clarification has emerged. Until such time as a useful definition becomes available or until HSE have issued appropriate guidance it is suggested that a competent person can be regarded as someone who:

(i) can demonstrate an adequate level of theoretical knowledge and practical understanding of local exhaust ventilation plant,

(ii) has sufficient experience to enable him to identify faults and defects in the construction, operation and performance of plant, and

(iii) can assess the significance of any faults or defects found in the context of the continued effective and safe operation of the plant.

At present it is understood that HSE is preparing guidance on competent persons and their training and qualification.

It is not a simple matter to list requirements for theoretical and practical knowledge and for experience for a competent person. Table 4.2 in Chapter 4 contains a list of the broad areas of knowledge required for a hygienist to produce effective solutions to control problems. Not all these qualities are required for a "competent person" to examine and test local exhaust ventilation systems, but items 4-6 will be particularly relevant. Although suitable formal qualifications may indicate an acceptable level of understanding, they should not be considered to be a necessary requirement for competence as appropriately experienced but "unqualified" persons may be equally capable of undertaking the work. Some attributes of a competent person can, however, be described in general terms, for example:

(i) an ability to operate the measuring instruments used in the assessment of local exhaust ventilation systems, to interpret the results obtained, and to understand their significance,

(ii) an understanding of the principles of operation of local exhaust ventilation systems,

(iii) an awareness of the health risks of the process and the degree of control to be achieved,

(iv) a general understanding of the main plant and its inter-relationship with the local exhaust ventilation control system,

(v) a knowledge of other specialist services that may be available (for example to assess personal exposure) and when these services should be called upon.

Competence can be acquired either by formal training in specific topics or by general technical training/qualification and suitable experience. There is a variety of routes by which a person may arrive at an acceptable degree of competence, which helps to explain why there has been difficulty in the past in producing a comprehensive definition of a "competent person".

11.3 Assessment of System Performance

Local exhaust ventilation systems are designed to capture or collect airborne contamination given off by a process and to convey this contamination to a point where it is either removed from the system (by filtration, scrubbing etc) or discharged to atmosphere. The overall performance of the system can therefore be considered in terms of the achievement of a series of objectives, the most important of which are:

(i) an acceptable level of control of the contaminant at all sources of emission,

(ii) effective conveyance of the contaminant away from the process,

(iii) disposal of the contaminant in a safe manner.

These aspects are to some extent independent, as it is possible to achieve satisfactory performance in one area, but not in another. For example, a well designed fan and ducting system will effectively remove any given quantity of air from the working environment, but unless such a system is connected to efficient hoods which provide the degree of control required at the process itself, little good will result. Similarly, if an inadequate filtration system is used or the system discharges to atmosphere at a point where people are liable to inhale the discharged air, the system does little more than move contamination from one place to another.

11.3.1 Qualitative Assessment

The degree of control achieved by the collection/capture system is best assessed by direct observation under actual operating conditions. However this is not always possible and indirect assessment may be all that can be achieved in some cases. Direct observation where the contaminant is a dust is possible using a dust lamp, which is described in Section 3.7.2. This technique enables fine dust particles and fibres normally invisible to the unaided eye to be seen, and allows the capture/collection efficiency of a hood to be assessed subjectively. It is important that such an assessment should be made under typical operating conditions, as many disturbing factors, such as the movement of an operator, motion of machinery, and turbulence created by general ventilation plant may affect hood performance.

If the use of a dust lamp is not practicable (eg when flammable hazards exist) or when the contaminant is a vapour and therefore not visible, less direct methods must be used. Additional information can be obtained from smoke tests which enable visual observations of flow into hoods to be made. Smoke test results need to be interpreted with care, however, as the smoke may not behave in the same way as the contaminant, particularly where large volumes of high or low density vapours are involved. As with the dust lamp, smoke tests should be performed under typical conditions of plant operation.

Air velocity measurements at the entries to paint spray booths and at fume cupboards, for example, may be made and compared with published and recommended standards for extraction. However, these measurements do not in themselves guarantee any degree of control, although the standards to which they are compared may reflect a considerable body of practical knowledge and experience and can therefore suggest a reasonable performance.

Smoke tracers can be used in a number of ways to reveal air movement and indicate where contaminant may be escaping in quantity (see Appendix 2 for a list of suppliers). Tracers can be used for a number of purposes including:

(i) Roughly defining the capture distance of a captor hood by releasing smoke in the vicinity of the source and on the side of the source remote from the hood.

(ii) Checking for leakage from canopy hoods and exhaust ventilation ductwork. Large volumes of smoke are normally required for this purpose and smoke canisters or generators should be used (see Section 3 in Chapter 3).

(iii) Airflow generated by the process or external sources can be revealed and either abated or taken account of in the system design.

When using smoke tracers to assess qualitatively the effectiveness of exhaust ventilation hoods it is important that the tests are done with the process operating. Work processes often induce airflows or increase air turbulence and a misleading impression of the effectiveness of an exhaust system can be gained if tests are done when the process, which is nominally controlled by LEV, is not running.

Smoke tracers are very simple yet powerful methods of assessment especially when used in conjunction with photography or video recording. Used properly they can demonstrate the effectiveness of a well designed system to workers and management or reveal the unsuspected yet restricted influence of a captor hood, the effects of cross-drafts and the results of novel or unplanned work procedures.

11.3.2 Quantitative Assessment

It may be possible to make a quantitative assessment of the performance of an extract system by estimating the degree of control that the system provides. Some form of atmospheric sampling is required for these assessments, which need to be undertaken with care if reliable results are to be achieved. There are two possible methods which can be used:

(a) atmospheric sampling of the contaminant produced by the process under typical conditions of use, or
(b) tests involving the use of a tracer substance.

Direct sampling of the contaminant involved in the process has a number of inherent difficulties which must be overcome if the method is to be successful. In the first place, atmospheric sampling will indicate the concentration of the contaminant at the sampling point, but by itself will give no information on the source of the contaminant. In addition, there will be a general background concentration of the contaminant in the workroom air which will tend to obscure measurements aimed at detecting leakage from a particular LEV hood. In extreme cases, a well-designed and efficient hood could erroneously be shown to have a poor capture performance by atmospheric sampling which picked up airborne contamination from other sources (for example, leakage from other hoods or from nearby open-topped drums). Some of these potential problems can be overcome by careful selection of equipment and sampling locations. As an alternative to conventional static sampling it may be possible, depending on the contaminant, to use direct-reading instruments (eg infra-red gas analysers and particle counters) to measure concentrations of the contaminant at various points. These instruments allow detailed surveys to be made fairly quickly and can be used to build up an overall impression of hood performance. Whatever technique is chosen, assessments of hood performance by direct measurement of the contaminant produced by the process should be undertaken with great care, by well-experienced hygienists who are familiar with the whole process. It should be noted that a sampling exercise designed to give useful information on LEV system performance will tend to be very different from one which is concerned simply with assessing personal exposure to a contaminant.

The alternative method, using some form of tracer, offers advantages of greater precision and reliability, but has its own drawbacks. Its principal disadvantages are that it is time-consuming, may be expensive, and requires a high degree of specialised knowledge and experience. Recent studies HAMPL and SCHULMAN (1985) have confirmed that gaseous and particulate tracers of different sizes do behave similarly though results for the gaseous tracer had to be corrected for particles > 3 μm in diameter. It may be possible to develop a simple relationship between the hood performance characteristics obtained with different tracers.

Common Problems

Tracer techniques are used as standard methods for assessing the performance of vacuum cleaners (BS 5415) and air filters (eg BS 3928) and are well-established for these purposes. However, attempts to develop a similar technique for laboratory fume cupboards have not been successful to date, as the draft test method did not give sufficiently reproducible results. In view of this mixed success, it is considered unwise to regard tracer tests as a universally applicable and reliable method of assessment at present. There is interest in tracer techniques and future developments may produce more generally applicable test methods which can be routinely applied to LEV hoods (see for example reference ?)

Information on designing exhaust ventilation systems is contained in Chapter 10 of the Guide. In order to assess whether the design performance is achieved, measurements of air velocities, flow rate and pressures will be required. These are obtained by the use of anemometers, pitot tubes. with anemometers. Anemometers are direct reading instruments, either of the hot-wire type which indicate the air velocity at a point, or of the rotating vane type which are larger and react more slowly than the hot wire devices and therefore give a measure of the average air velocity. In conjunction with physical measurements or duct cross-section, velocity traverses can be used to estimate the volume flow rate of air to a duct, booth entry etc. Duct flow measurements can also be made using pitot tubes, and a general procedure for these measurements is given in BS1042, BSI (1983). In assessing system performance where the contaminant is a dust, it is important to ensure that the air velocity is sufficient to convey the dust to the filters (see Section 10.1.2). If the velocity falls below a certain level, dust will settle on the bottom of horizontal ducts, on ledges, dampers etc and will not be discharged from the system. The dust may continue to build up, causing additional problems and eventually reducing the performance of the system due to blockage.

The removal of contaminant from the extracted airstream is often to be preferred to its discharge to atmosphere . The method of removal depends on the nature and characteristics of the contaminant. Dusts for example can be removed by mechanical filters, electrostatic precipitators, cyclone separators or wet dusting equipment. Vapours, however, will pass through filtration media but can be absorbed into liquids (eg in scrubbers) or in solids (eg activated charcoal filters). Performance of all these devices can be assessed by various means such as measurement of pressure drop across filters, determination of filter efficiency and atmospheric sampling at the stack outlet. If discharge to atmosphere is contemplated then detailed consideration will need to be given to matters such as the height of stack, local prevailing wind conditions or nearby work activities and residential areas.

11.4 Commissioning

Commissioning is the procedure by which a local exhaust ventilation system, which has been installed or modified, is started up and demonstrated to meet its performance specification. The commissioning procedure should therefore always include some means of assessing the system performance. When large-scale building services systems are installed, commissioning tests are a fundamental part of the process by which hand-over from installer to user takes place and it is only after the system has been seen to work effectively that the installer's contractual responsibilities are considered to be fully discharged. The same considerations should apply to industrial ventilation systems designed to control airborne contamination, and a commissioning procedure should always be followed so that the system can be seen to achieve the desired performance.

Procedures to be followed in commissioning any ventilation system will vary with the complexity of the system, but should adhere to the broad principles set out below. Detailed information is given in the Commissioning Code published by CIBSE (1978, 1982) and in BS5720: 1979 (BSI, 1979).

In order to meet the objectives of the commissioning procedure comprehensive engineering data for the system will be needed. In particular the following items will be required:

(i) the original design specification for the system,

(ii) detailed drawings of the system as installed,

(iii) manufacturer's installation and operation manuals for the various components in the system (eg fans, filters) where appropriate.

In addition to the above, it may be useful to have access to standard works of reference and design data.

A local exhaust ventilation system is intended to provide protection against exposure to airborne contamination for persons working with substances hazardous to health. It is also important to protect to the same extent those who install and maintain the system. As commissioning tests may well involve taking measurements inside ducts, adjusting hoods etc, it will be necessary to assess the likely exposure to hazardous substances of persons undertaking this work and to provide them with protective clothing and respiratory protective equipment as appropriate.

Before the plant is started for the first time, it will be necessary to carry out some pre-running checks to verify that all the elements of the system are in position and that rotating parts are free to move. The following check list may be used as a guide:

(i) the position of the hoods and other inlets should be verified as being correct and ductwork should be examined internally to see that there are no obstructions,

(ii) fire dampers should be open, explosion relief panels (where fitted) should be checked and all inspection doors should be closed and fastened,

(iii) ductwork joints should be examined visually for tightness and ductwork supports should be checked,

(iv) air-cleaning devices should be examined internally and externally and the operation of mechanical parts such as bag-shaking mechanisms should be checked,

(v) fans and motors should be examined to ensure that they are free to rotate. The tension of belt drives should be checked and adjusted where necessary and all guards should be secured in place. Bearings should be lubricated as required in manufacturers' manuals. The direction of rotation of fans can be verified by switching them on and off. Particular attention should be given to wiring connections in the case of 3-phase motors, as connecting phases in the wrong sequence can produce rotation in the wrong direction. Centrifugal fans generate a lower than specified but detectable <u>forward</u> airflow when running backwards, so care should be taken to ensure that the direction of rotation is in accordance with the manufacturer's instructions.

Once the pre-running checks have been completed successfully, the plant can be started up and commissioning tests carried out. Any commissioning instructions given by individual component suppliers should be followed. These may include such matters as setting the initial timing and period of shake on bag-shake mechanisms. Checks should also be made of the functioning of all mechanical and electrical equipment to ensure that bearings are not overheating and that there is no undue vibration or noise from the system. At this stage initial air flow measurements can be made, compared with the original design specification and appropriate adjustments made.

Once the system has been run in for some time, perhaps a few days, final commissioning performance tests can be made and the system adjusted as necessary until the design specification is shown to be met. This procedure should involve an assessment of the level of contaminant control achieved and will include air flow measurements, air sampling and the use of visualisation techniques such as the dust lamp, as necessary.

On the completion of the commissioning tests, detailed records should be made of the system performance and the tests carried out, and these should be passed with the drawings, specifications and manuals to the user for safe keeping as part of the formal handover procedure.

11.5 Maintenance

The purpose of maintenance is to keep the ventilation plant operating at optimum efficiency and in a state of good repair. The overall aim should be to maintain the plant in this condition at minimum cost and this will be most easily achieved if maintenance requirements are considered in detail at the design stage (see Chapter 10, Section 10.7). An example of the importance of design for ease of maintenance applied to exhaust ventilation in foundries is given by DEWELL (1979). Not only is it considered bad practice to rely on "breakdown" maintenance, but there will usually be a legal obligation to make sure that local exhaust ventilation plant is kept operating effectively. Maintenance should therefore be both planned (ie organised and controlled with the use of records to a pre-determined plan) and preventive (ie carried out at pre-determined intervals with the intention of reducing the likelihood of an unacceptable loss of performance).

A primary requirement for an effective preventive maintenance programme is that it should be managed and operated by properly trained and competent staff. If untrained staff are employed on maintenance, or if supervisory staff do not have sufficient authority to ensure that the maintenance plan is carried out, the system will have little hope of success.

Table 11.2 lists current health and safety legislation requirements for the examination and testing of local exhaust ventilation systems by competent persons at specified intervals. There are generally additional requirements for any defects found to be reported and rectified without undue delay. These requirements do not constitute effective preventive maintenance and should be seen as additional checks on the continued satisfactory performance on the plant

Table 11.2
Legislation currently requiring regular examination and testing of local exhaust ventilation plant in the United Kingdom

Legislation	Regulation	Requirements
The Asbestos Regulations 1969*	Reg 7(3)	Weekly inspection. Thorough examination & test every 14 months by a competent person.
The Blasting (Castings and Other Articles) Special Regulations 1949	Reg 11	Weekly inspection. Thorough examination and test every month by a competent person. Defects to be remedied without delay.
The Chromium Plating Regulations 1931	Reg 1A	Efficiency of extraction to be tested by appointed responsible person every 14 days.
The Grinding of Cutlery and Edge Tools Regulations 1925	Reg 4	Examination and test every 6 months by a competent person. Defects to be remedied as soon as practicable.
The Grinding of Metals (Miscellaneous Industries) Regulations 1925	Reg 17	Examination and test every 6 months by a competent person. Defects to be remedied as soon as practicable.
The Jute (Safety, Health and Welfare) Regulations 1948	Reg 10(2)	Extract ventilation plant to be maintained in good repair by occupier.

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	Reg 10(3)	Examination and cleaning every month or more frequently as necessary to maintain plant in efficient working order.
The Control & Lead at Work Regulations 1980	Reg 14	Control measures to be maintained in good repair by employer as far as practicable. (NB. Associated Approved Code of Practice requires weekly visual checks and competent persons to undertake annual thorough examination and test of extract systems).
Non-Ferrous Metals (Melting and Founding) Regulations 1962	Reg 12(1)	All extract ventilating plant to be properly maintained.
	Reg 12(2)	Thorough examination and test by a competent person every 6 months. Defects to be reported to occupier.
The Pottery (Health and Welfare) Special Regulations 1950	Reg 17(8)	Thorough examination and test every 14 months by a competent person. Defects to be recorded.

A suitable system of records is an integral part of a good maintenance system. A commercial automated recording and prompting program exists (STOTT and PLATTS, 1986), and any system should include the following items:

(i) a basic inventory of the system giving details of all equipment as installed and including design specification, system drawings, suppliers' instruction manuals etc,

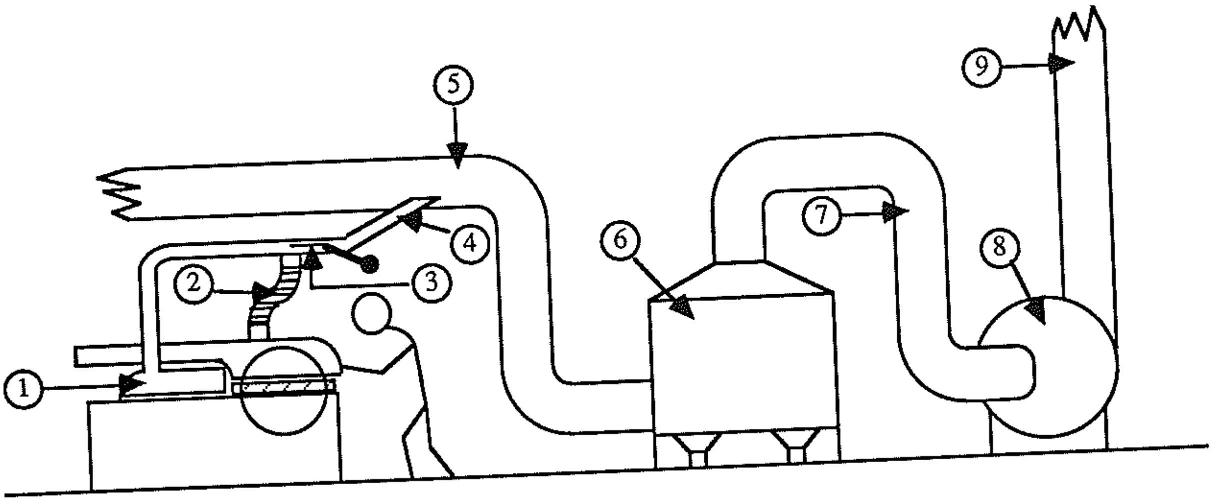
(ii) inspection and maintenance schedules for all items of plant indicating maintenance work required and the intervals at which it is to be carried out,

(iii) a logging system to record the work which is actually done and any comments, difficulties encountered etc,

(iv) a planning system to indicate when specific items of work are required. The frequency of checks and maintenance should be established from operating experience and information supplied in manufacturers' operating manuals. Although such manuals often provide detailed information on maintenance schedules, they are drawn up for average operating conditions and may need to be modified in the light of experience. Maintenance programmes should be drawn up to list work required at daily, weekly and monthly intervals with additional specifications for major overhaul as necessary. Table 11.3 gives some additional information on typical maintenance schedules.

* These regulations will be superseded by new Asbestos Regulations which were issued in draft form in 1985.

Table 11.3
Maintenance schedule for local exhaust ventilation plant serving a woodworking machine shop



Item	Maintenance work required	Frequency
1 Extract hoods	Inspect for damage, check for correct position and adjust as necessary.	D/W
	Test dust collection efficiency.	1/2 A
2 Flexible trunking	Inspect for damage, renew as necessary.	D
	Check connecting clips and seals.	W
3 Branch damper	Check damper is open while machine is operating.	Continuous
	Check that damper is free to move.	W
4 Branch duct	Check joints for tightness.	Q
	Check supports & brackets for damage.	Q
5 Main duct	Check joints for tightness.	Q
	Check supports & brackets for damage due to mechanical impact, vibration etc.	M
6 Filter plant	Check pressure drop.	D
	Inspect filter bags for damage and wear.	D/W
	Replace as necessary.	
	Check operation of shaking mechanism	M
	(including motors), reverse jet system etc.	M
	Lubricate motor bearings.	as recommended by supplier
	Major overhaul.	A

	Common Problems		
7	Ducting between filter and fan	Check joints for tightness.	Q
		Check supports and brackets for damage due to mechanical impact, vibration etc	M
8	Fan	Lubricate bearings.	as recommended by supplier
		Inspect blades for wear damage.	1/2 A
		Inspect motor for excessive vibration or noise or high temperature.	1/2 A
		Check soundness of electrical connections.	1/2 A
		Check earthing.	1/2 A
		Check mountings.	1/2 A
		Check brushes if fitted.	1/2 A
		Check tightness of duct connections.	A
9	Discharge ducting	Check joints for tightness.	Q
		Check supports and brackets for damage due to mechanical impact, vibration etc.	M
		Check ductwork external to building for weathering and corrosion.	1/2 A
		Inspect discharge terminal for damage.	1/2 A

Notes:

1 This schedule of maintenance should be followed <u>in addition to</u> any requirement for statutory examination and testing of the local exhaust ventilation plant.

2 Statutory examinations may require assessments of the effectiveness of dust control at extract hoods, using a dust lamp or air sampling techniques.

3 Airflow measurements to determine whether the extract system continues to meet its design specification are recommended at intervals not exceeding 6 months, and whenever significant modifications are made to the plant.

4 When undertaking repair work, always refer to manufacturer's handbook.

5 In the above table: D = daily; W = weekly; M = monthly; Q = 3 monthly; 1/2 A = 6 monthly.

Wherever maintenance is undertaken, the work should be carried out in such a way as to ensure compliance with statutory requirements for health and safety and should involve the use, where appropriate, of a permit-to-work system and of suitable protective clothing and respiratory protective equipment.

11.6 References

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STOTT, M.D. and PLATTS, P.J., (1986), The ventdata ventilation plant monitoring and maintenance system. In Goodfellow, H.D., Ventilation '85, Proceedings of 1st International Symposium on Ventilation for Contaminant Control, October 1985, Toronto, pp145-152; Chemical Engineering Monograph 24, Elsevier Science Publications, Netherlands.

12

ANNOTATED BIBLIOGRAPHY ON AIRBORNE CONTAMINANT CONTROL

12.1 Introduction

There is no one text which covers all aspects of airborne contaminant control which could be classified as **the reference text.** All books cover some aspects in more detail than others and which are appropriate will depend on the reader's specific needs.

In this bibliography we have tried to collect together the common and not so well known texts on air contaminant control. Most of the works are concerned with ventilation, local and general, and we have in most cases tried to give the reader an idea of the depth and orientation of the texts listed. Some are more concerned with processes and others are written by or for particular organisations and deal with control applied in certain industries. Some books are out of print but still of great relevance. These can be obtained through reference or college libraries via the British Lending Library, Inter-Library Loan Service (in the UK) and the ISBN number should be quoted to facilitate the librarian's work.

By careful choice, using the bibliographic notes where they exist as a guide, readers should be able to select the texts which are likely to cover their specific needs in detail.

In addition, a list of papers which cover control of airborne contaminants has been compiled from the Annals of Occupational Hygiene and the American Industrial Hygiene Association Journal (1975-mid 1986).

12.2 Process Information

Industrial Hygiene Aspects of Plant Operations, Volume One. Process Flows. 1982. Editors: L.V. Cralley and L.J. Cralley. McMillan Publishing Company, (USA), Collier McMillan Publishers (UK) ISBN: 0-02-949350-1. 360 Pages.

This book contains descriptions of 63 primary production processes by individuals, mainly hygienists, who are responsible for the operations they describe. All chapters are illustrated by flow diagrams and some have photographs of specific processes. The main contaminants likely to be of interest to the hygienist are identified but little information is given on the average or range of exposures which can occur. Also, few chapters are referenced. The 63 chapters contain a wealth of experience and make this text a useful reference work and starting point for the hygienist dealing with a new process.

Annotated Bibliography

Industrial Hygiene Aspects of Plant Operations. Volume 2. *Unit Operations and Product Fabrication. 1984. Editors: L.J. Cralley and L.V.Cralley. Macmillan. ISBN: 0-02-949350-1.*

This book follows on from Volume 1 on Process Flows and is again edited by Cralley and Cralley. Each chapter is written by someone with practical knowledge of the processes which are described.

The book starts with a thought provoking chapter entitled "The engineer's responsibility in occupational disease prevention" and continues with a description of 25 Unit Operations and 14 Product Fabrication Operations. While not fully comprehensive a large number of common operations are covered and the editors promise that additional processes will be covered in succeeding editions. Each chapter, besides supplying a good basic description of the tasks and processes involved at Unit or Fabrication Operations, also lists the hygiene problems which may occur at each stage and, in many chapters, tries to assess the likely problems which may occur at each stage and, in many chapters, tries to assess the likely order-of-magnitude a particular hazard may pose and how it may be controlled. Individual chapters vary in quality depending upon the author. Almost all give succinct descriptions of the processes, some only skim through hygiene aspects whereas others go into detail. None unfortunately, are referenced.

This volume complements the first and covers the following Unit Operations: aluminium metal working, electroplating, fluidised bed drying, industrial centrifugation, separation and filtration, metal cleaning, foaming and working, mixing and blending, non-destructive testing, painting and coating, plastic processing operations, rubber curing, compounding, mixing, extruding, calendering and milling, spray vacuum and freeze drying, welding operations and woodworking operations. Product fabrication operations covered include: colour photography, construction equipment, glass lense manufacture, jet engine manufacture, lead acid battery manufacture, semiconductor manufacture, robot manufacture, tyre manufacture and metal can manufacture.

Industrial Hygiene Aspects of Plant Operations. Volume 3. *Engineering Considerations in Equipment Selection, Layout and Building Design. 1985. Editors: L.V.Cralley and L.J.Cralley. Macmillan (US)/Collier Macmillan (UK). ISBN 0-02-949370-6.*

This is by far the most detailed and in many ways the most useful of the 3 volumes in this series. The book starts with a chapter on how to examine processes and materials and the likelihood that control will be needed and goes on in the next two chapters to look at the characteristics of open and closed systems. There follows a long chapter on the "Selection and Management of Process Equipment" which covers conveyors of various types, crushers and grinders, reactors, pumps and tanks, mixers and blenders, furnaces and dyers, centrifuges, filters, container filling, electroplating and air cleaning. The next chapter reviews Building Types and their advantages and disadvantages which is followed by a chapter on general ventilation which examines both natural and forced examples. The next 3 chapters are very perceptive and often omitted from texts on air contaminant control. They cover noise control on ventilation equipment, maintenance and a very timely chapter entitled "Engineering is Necessary but not Sufficient" which details the management and administrative system which should support the engineering solutions. In the next sixteen chapters the principles elaborated in the early part of the book are applied, by separate and knowledgeable authors to certain processes, industries and the handling of certain substances. These include: aluminum smelting, asbestos mining, milling and manufacture, chrome chemicals production, copper and brass alloy foundries, semiconductor manufacture, fluorine, flat glass, grain handling, hydrochloric acid, isocyanates, lead-acid battery manufacture, primary and secondary lead smelting, mining and milling, paper production and the handling of casting sand in foundries.

The chapters vary in detail and the authors concentrate on the approach adopted in the USA which is probably inevitable. Each chapter is well referenced but again these are all from North American sources. Nevertheless the approaches used will be similar and the detailed engineering and work method organisation need not be copied slavishly but can be used as food for thought.

Organic Chemicals Manufacturing Hazards. 1981. A.S. Goldfarb, G.R. Goldgraben, E.C.Herrick, R.P.Ouellette and Cheremissinoff. Ann Arbor Science Publisher Inc/The Butterworth Group. ISBN 0-250-40409-5. 430 pages.

The authors are concerned with the "hazards associated with the substances present in processes and effluent streams". They do not consider "equipment hazards" and concentrate on chemical hazards which are broken down into four categories; flammability, explosiveness, toxicity and corrosiveness. Each of the nine chapters deals with a different production process and include the production of: acetic acid, acetaldehyde, dL-methionine, tetra-alkyl lead, vinyl chloride, chlorophenols and vinyl acetate. Each chapter is referenced.

The book contains a lot of information on the chemicals that are likely to be encountered, and their physical states, during the manufacture of the materials listed. The authors rely solely on Sax's "Dangerous Properties of Industrial Materials" for their information on toxicity and do not appear to have consulted the occupational hygiene literature, which is a pity. Probably because it is a multi-author work, the editors have insisted upon a style which is rigidly the same throughout the book. Standard introductions are repeated with minor alterations in each chapter which is tedious. The authors are mainly concerned with circumstances in the US, but much of the material is universally applicable. For those designing or inspecting the process plants covered, this is a useful though not complete reference.

Recognition of Health Hazards in Industry - A Review of Materials and Processes. 1981. W.A. Burgess. John Wiley and Sons. ISBN: 0-471-06339-8. 275

Described by the author as an introductory text for an audience not familiar with industrial processes this book, in fact, contains a lot of material of use to the practising hygienist. A variety of common "Unit Operations" are first described, 15 in all, ranging from Abrasive Blast to Welding. These are followed by 32 shorter sections on specific production facilities. Materials and processes are discussed, likely release points of contaminants are described, and an attempt has been made to supply some information on the likely levels involved. Each section is referenced but not comprehensively, also the material is mainly derived from US sources though not exclusively.

12.3 General Texts on Ventilation (alphabetical order by first author)

Industrial Ventilation - A Manual of Recommended Practice, 18th Edition, 1984, Committee on Industrial Ventilation, American Conference of Governmental Industrial Hygienists. Cincinnati, Ohio, USA,344 pages.

This is the standard American text on Industrial Ventilation now into its 18th Edition. New editions appear roughly every 2 years. The early chapters cover General Principles of Ventilation, Dilution Ventilation, Ventilation for Heat Control. The major contribution the book makes is in Chapters 4 and 5 on Hood Design and Specific Operations in which some 60 or more examples of applications to specific industrial problems are given with diagrams, recommended volume flow rates and associated pressure losses. The book is unique because of Chapter 5. Unfortunately the units are imperial and hood design data are still based on the work of Dallavalle which has now been superceded by the work of Fletcher in the UK. Later chapters cover Duct Design Procedures, Make up and Recirculation Air, Construction Specifications, Testing of Ventilation Systems, Fans and Air Cleaning Devices. Duct pressure loss calculations are based on the equivalent length principle popular with USA designers rather than the velocity pressure method favoured by the British designers.

In spite of the dated system of units employed, this book is invaluable for ventilation designers.

Annotated Bibliography

Design of Industrial Ventilation Systems. 1982. Alden, J.L. and Kane, J.M. 5th Edition, Industrial Press. ISBN: 0-8311-1138-0

This work has been updated and revised several times since it first appeared in 1939 when it was hoped that sufficient data would be presented to permit the design, or appraise the claims of, an exhaust ventilation system. The general guide covers local exhaust systems, piping and structural details, collectors, fans, low pressure conveyors and monitoring of systems. The fifth edition has been extended to include general exhaust ventilation and makeup air supply, energy conservation, and isolation of the workplace from major contaminant generation zones. It includes applications to various chemical processes and material handling problems.

This is a classic guide, clearly written though dated in places. Imperial units are generally used throughout and this is perhaps an area for further revision.

Control of Airborne Dust. W.D.Bamford, The British Cast Iron Research Association, Alvechurch, Birmingham, England1961.

This book describes work done during the 1950s and published in 1961 on the control of dust at certain foundry processes and relates to foundry conditions and practices current at that time.

There are valuable illustrations of the thermal lift and dust plumes produced by hot castings or hot moulding sands together with the velocity of cross draughts or capture velocities that are necessary to deflect the rising plume. These data are still valid and are applicable to other situations.

There are also considerable data on the air-flow pattern and the design of various forms of knock-out hoods.

The book also contains information on the air-flow pattern around swing frame grinder wheels together with the design of a booth for the control of dust from this machine. The design of the integral exhaust system for this machine has generally superseded the case of booths for this application.

The book also includes general information on fans and filters and their application to dust control but this is, of course, limited to the date of publication.

Fundamentals of Industrial Ventilation. 3rd Edition. 1972. V.V. Baturin. Pergamon Press. 48 pages. Out of print (though available on microfiche).

This book is a translation of the 3rd Edition of Baturin's book which was first published in Russia in 1965 for "ventilation engineers and technologists, scientific workers and technical workers of central committees of trade unions". The book covers all aspects of industrial ventilation including general and local ventilation, control of the thermal environment and air contaminants and air jets. It does not cover the design of ductwork systems or the practicalities of air contaminant control. It is more of an academic text but none-the-less contains a lot of useful knowledge. It is particularly good on air jet theory and the design of air douches and contains some nice visualisations of airflow in buildings and enclosures.

Most, if not all, the references cited are by Russians and in Russian. No reference is made to work done by engineers and others in the Western world or indeed any other country bar Russia. Yet there is suggestive evidence of a certain amount of plagiarism. Thus the 3-dimensional diagram of velocity contours at a rectangular opening is an almost exact if not perfect copy of Dallavalle's work (p 11 in Dallavalle and p 147 in Baturin). This may be due to the fact that the author is citing earlier Russian work and it was the original author who "borrowed" from the West. It is a pity though that other non-Russian authors are not openly recognised. Despite this irritating habit there is much of use in this book, and the author's approach to problems is often novel and thought provoking, and it is probably the most comprehensive source when it comes to air jets and douches, an approach to exposure reduction not sufficiently exploited in the West.

Annotated Bibliography

Ventilation Handbook for the Rubber and Plastics Industries. 1979. G. Cheater, J. Quallington, P. Dolbey and P. Jackman. R.A.P.R.A., Shrewsbury, Shropshire, 101 pages.

This book is somewhat longer and more technical than "Clearing the Air" and covers the same territory. It was produced, "in a short space of time in an attempt to avoid duplication of effort by different sections of the industry". The authors have attempted to cover a large topic in a small book and some areas are necessarily skimmed over. However there is a lot of useful practical advice on control of dust and fume in the rubber industry. The worked examples, the list of dust suppressed chemicals and the short chapter on selecting a contractor are particularly useful. The references are not well described and incomplete in their coverage. Also it is a pity that the Fletcher's work on captor hoods is not referred to while the ACGIH's approach to hood design is described but not creditted. A useful starting place for those working in the industry.

The Performance, Installation, Testing and Limitations of Microbiological Safety Cabinets. Occupational Hygiene Monograph No 9. R.P.Clark (1983). Science Reviews Ltd. ISBN 0-905927-16-8. 106 pages.

The title adequately reflects the contents of this book. The author works at the Laboratory of Aerobiology, MRC Clinical Research Centre, Harrow and has a great deal of experience in the field. This is well demonstrated in the historical introduction which explains the developments which have lead to the present day Class I, II and III Safety Cabinets. The following chapters comprehensively cover the relationship between airflow and cabinet performance, filter tests, the choice and installation of cabinet, cabinet sterilisation and the construction of rooms which contain cabinets. The appendix discusses the results of contaminant tests applied to fumecupboards and provides an example of a redesign which reduced fumecupboard effectiveness.

The lessons learnt in the design of Safety Cabinets including airflow monitoring and contaminant testing could be applied beneficially to the design of many other types of local exhaust ventilation equipment.

The text is well referenced and this monograph will definitely be of much use to all those interested in or with responsibility for microbiological safety. In addition it also contains general lessons for the person interested in exhaust ventilation design generally.

HHSC Handbook No 2, 1986. Fumecupboards Revisited. J.D.Cook and D.Hughes, H & H Scientific Consultants Ltd, (ISBN 0-948237-01-5). iii + 79 pages, 30 figures, 55 references.

If one can have sequels in technical books this is one. It usefully follows the Science Reviews Monograph No 4, A Literature Survey and Design Study of Fumecupboards and Fume-Dispersal Systems by D. Hughes published in 1980. As with the previous one this little book represents many years experience of the authors in the field and gives a very practical update on the installation, operation, maintenance and removal of fumecupboard systems. The thirteen chapters with their novel titles have a useful range of subject matter for example: the problems of ensuring good airflow patterns over the face, the ability of the device to contain the contaminants and to withstand an explosion, advice on maintenance and the dispersal of the extracted air. An excellent chapter on how to tackle the daunting problem of removing an old fumecupboard adds to the value of this book although I believe the chapter on energy aspects of discarding heated air from a building could have been expanded. There are thirty seven new references quoted which were not included in the Occupational Hygiene Monograph No 4. I can recommend this book to anyone who uses or has responsibility for fumecupboards including those who are even remotely considering purchasing one.

Review of Air Pollution Theory. 1976. M.Crawford, McGraw Hill, London. ISBN 0-07-013490-1. 624 pages. (With respect to Industrial Ventilation Systems).

This is a 600+ page volume of tightly packed text and diagrams on the wider subject of air pollution control. It is to be commended to hygienists as a useful reference and training volume.

The introductory chapter covers scope of the subject, the nature and measurement of pollutants, relevant SI units, and conversion factors (from US units), as well as an example of system costing.

Chapters 2 and 3, covering the principles of fluid flow and dynamics of particles in fluids, are necessary knowledge for hygienists, as is the calculation of concentration of a pollutant in an enclosure with controlled air supply (the Author does caution the user in applying dilution ventilation).

Chapter 4 discusses pollutant distributions according to various parameters, relate these to efficiency of their collection, and tends to be mathematical.

The design of industrial ventilation systems is covered succinctly in a chapter of 70 pages, with 23 worked examples. The section on hood design (17 pages) is straightforward, showing the calculation of control velocities from the area of the capture surface for simple openings, and for double slot and annular slot hoods. Design of ductwork is covered in 16 pages, and fan selection based on performance in 21 pages. The important point is made that the system must be designed to be stable in operation.

The following 9 chapters are devoted to collection systems and are also highly relevant to occupational hygiene.

The book offers a balance between mathematical analysis and practical applications, but only 8 references are give on industrial ventilation - 4 of which are to the works of Hemeon.

Exhaust Hoods, 2nd Edition, 1952. J.M.Dallavalle. The Industrial Press, New York, 146 pages (out of print).

Dallavalle was the first person to study systematically the flow of air into exhaust hoods. He did the work for his doctoral thesis on the subject in the late 1920's at Harvard School of Public Health under the supervision of Theodore Hatch, and published the results of the research in the early 1930's. His work, together with Silverman's on exhaust slots in the late 1930's laid the theoretical and empirical bases of exhaust ventilation. Although the empirical work has been improved upon Dallavalle's work is still fundamentally sound and his book contains a wealth of useful insights for the exhaust ventilation designer. The first three chapters describe the theory of air flow into hoods. The next chapter is entitled "Criteria for Determining Hood Effectiveness", a subject often missing from more modern text books. The author has the following to say: "To determine the effectiveness of a given hood, it is necessary to evaluate the concentration of the substance being collected which remains in the air and is constantly breathed by the worker", (p 38), and he continues on the next page, "Hoods are of no value in the prevention of occupational disease unless they eliminate the hazard". The need to link exhaust ventilation design to hygiene measurements of exposure is unfortunately still often missing today and yet the need for it has been appreciated for decades.

Chapter 5 considers canopy hoods and Chapters 6-8 hoods for dust control, while Chapters 9 and 10 deal with fume, gas and vapour control. The next 5 chapters (11 - 15) describe hoods for specific processes and the basics of hood construction.

This book is now out of print but may be available in reference and college libraries and is available via the British Lending Library (see Appendix 4). Although dated it still contains much of value.

Woods Practical Guide to Fan Engineering, 1985. B.B. Daly, Woods of Colchester Limited, 370 pages.

The value of this book is ably summed up in the Foreward written by the Managing Director of Woods.

"This completely revised Woods Guide, like its predecessors, is aimed at the practical engineer rather than the expert and includes many worked examples of typical ventilation systems. It provides a more comprehensive compendium of information relating to fans, fan drives, fan selection and their environment of application. It commences with two chapters describing the ventilation requirements of the individual and of occupied spaces subject to various thermal environments caused by industrial, human and solar inputs. The next three chapters continue with a description of methods of heat rejection and heating, including discussion of such important current issues as pollution control and explosion hazards. The heart of the book - like the centre of the fan industry - treats extensively, in Chapters 6 and 7, the details of determination of system losses, fan performance specification and fan sizing. There the scope is not restricted to UK climatic conditions whilst, for the more mathematically-minded, the basic theory of fan pressure generation is included.

"An important feature of present-day society is the interest in efficient use of energy. Often fans are required to operate over their characteristic rather than merely at the flow corresponding to fan best efficiency. In such cases both the motor drive and the method of fan duty control are of primary importance. Chapters 8 and 9 provide clear illustrations of the merits of different electrical drives and fan duty controllers necessary to prevent unwanted energy dissipation. The increasingly relevant subjects of noise and vibration are dealt with in Chapter 10 and include methods for calculation of fan sound power and assessing vibration acceptability. The current interest and controversy in fan performance test standards is covered in the next chapter, together with the companion subject of inherent test accuracy or uncertainty depending on the commercial viewpoint. Chapters 12 and 13 are more specialist sections dealing with heat exchanger and drying topics and the problems of mine and tunnel ventilation. Lastly, a range of tables and charts is provided whose value and usefulness are enhanced by bringing together data on many topics within a single accessible reference".

It is a valuable text and should be widely used by occupational hygienists involved in the control of the working environment.

Advanced Design of Ventilation Systems for Contaminant Control. H.D. Goodfellow. Elsevier Science Publishers BV1985. (745 + XXV pp) ISBN 0-444-42546-2.

The author of this book is candid about his subject: "The industrial ventilation field is an engineering discipline which has been badly neglected for a long time. Research and development activities and technical literature in the field are sparse and highly fragmented", p 4. Based on this perception the book is an attempt to pull together the disparate literature on industrial ventilation and as such is the best attempt so far.

Chapter 1 covers the fundamentals of fluid flow and fluid particle systems. Chapter 2 examines the design parameters and technical specifications for the major equipment of ventilation systems for process buildings. Chapter 3 describes the design of industrial ventilation systems for process buildings. Chapter 4 covers the design of dust control systems using local exhaust ventilation. Chapter 5 presents the design of ventilation systems for fume control. Specialised ventilation techniques covered in Chapter 6 include dilution ventilation, recirculation of filtered air, enclosures of buoyant and non-buoyant sources, fume cupboards, welding fume control, air curtains, spray painting booths, exhaust systems for open surface tanks, and ventilation studies using tracer gas techniques.

The appendices include a list of 1984-1985 TLV's, design charts, an extensive section on technical specification of individual equipment items with questionnaires, and a standard calculation design procedure for fume extraction from an electric arc furnace.

The work is based on the author's experience of working with Hatch Associates Ltd and the University of Toronto and, as with any author, the text is most informative and thorough where the writer is describing a problem which he has dealt with personally. Thus the bias of the book is towards dust and fume control and the problems special to controlling gas and vapour contaminants are given far less attention. Two irksome omissions are the lack of a comprehensive index and the fact there is little cross-referencing. As the book is 745 pages in length this makes it hard work for the reader to use. Generally the illustrations are good though some, taken from other sources, have not reduced well. Also, this reviewer is not a great fan of word-processor generated text. There are inevitably a number of errors most of which are trivial but one of which is serious. Part of Fletcher's formula for predicting centreline velocity is incorrectly quoted (p 288);

a is in fact equal to $\frac{X}{\sqrt{A}}\left[\frac{W}{L}\right]^{-\beta}$

in the book the X is missing. Most books produced in the USA ignore the work of others in Britain and the rest of Europe, but the author, a Canadian, draws comprehensively on references from the UK and occasionally other countries.

This is a comprehensive text which requires persistance to get the best out of it. It does not always stand alone and the user will probably need access to a good reference library. It is highly recommended though at a price of ~ £120 this probably means persuading the library or your employer to buy a copy.

Ventilation '85 - Proceedings of the 1st International Symposium on Ventilation for Contaminant Control, October 1-3 1985, Toronto, Canada, Ed: H.D. Goodfellow. Chemical Engineering Monograph 24, 1986. Elsevier Science Publishers B.V. ISBN: 0-444-426221, 870 pages.

In 1982 Goodfellow and Smith wrote a review article on industrial ventilation (Am Ind Hyg Assoc J, V43, 3, pp 175-184). They concluded their review with two comments the first of which went as follows:

"We feel sure that there could be some real progress made in the industrial ventilation field if there was a concerted effort to review and study the technology in the industrial ventilation field on a world-wide basis. There may be some merit to organise an international symposium or conference on industrial ventilation which could provide a stimulus for interchange of ideas and practices", (p 181).

True to their word Goodfellow and the other engineers and industrial hygienists began, in 1983, to organise the conference. Almost two and a half years later it took place, 70 papers were presented and the symposium was attended by over 300 people, 50 of whom were from overseas. The book of the proceedings was out roughly six months after the conference which is a commendable achievement and the majority of papers are of good quality. The symposium was divided into 12 sessions which covered Advanced developments in ventilation, Control of toxic and explosive contaminants, Advances in tracer gas use, Ventilation for residential and modern office buildings, Ventilation for control of carcinogens and biohazards, Ventilation measurement and control, Source emission rates and filters, Air recirculation and energy conservation. The proceedings contain a wealth of new ideas and practices and the goal the organisers set themselves was more than realised.

The next international symposium on ventilation for contaminant control will take place in Britain in 1988 and will be organised by the British Occupational Hygiene Society (BOHS) and other interested bodies. The Canadian Symposium, judging by the quality of this book, will be "a hard act to follow!"

Industrial Ventilation and Air Conditioning. 1985. T.Hayashi, R.H. Howell, M.Shibata and K.Tsuji. C.R.C. Press Inc, Florida, ISBN: 0-8493-6227X, 228 pages.

This book is mainly based on the theoretical and experimental laboratory work of the Japanese authors. Their main concern has been with push-pull ventilation and an attempt to relate the efficiency of a captor hood to parameters other than hood geometry and air flow pattern. They have investigated source size and shape, rate of emission, and have done some work on the effects of side draughts. To do this they used numerical mathematical analysis and laboratory models.

The book is theoretical, rather dense to read and probably only of interest to the specialist.

Annotated Bibliography

Plant and Process Ventilation. 1963. W.C.L. Hemeon. Industrial Press Inc. New York. 447 pages. Out of print.

In many ways this is still the most accessible and useful textbook on exhaust ventilation that has been written. It is dated, it does not use SI units or draw upon non-USA sources and it is only available from reference or college libraries. However it is still worth thorough study. The author was one of the pioneer American industrial hygiene engineers in the 1930's and his book not only covers the theory of air contaminant control very well but it is full of practically based examples and experience which are still very relevant. Also, despite at times dealing with complex topics the text never seems dull or turgid. The explanation and examples are always clear. This book is well worth consulting.

A Literature Survey and Design Study of Fume Cupboards and Fume Dispersal Systems, 1980. D.Hughes. Science Reviews Ltd, ISBN 0-0905927-50-8 VI + 82 pages.

The author of this booklet writes from the standpoint of more than 15 years practical experience of the design and installation of fume cupboards. In the early chapters he covers, in some detail, basic principles of design and construction of various types of fume cupboard and describes associated extract and supply systems. These chapters contain many useful points although almost a page is devoted to an empirical formula for calculating the required face velocity before the author reaches the conclusion that: "values for the recommended face velocity calculated by this technique can vary quite widely and the formula does not appear to have been used subsequently perhaps because of the empirical nature of some of the parameters".

Chapter 4, on fume dispersal, contains many up-to-date references, as does the rest of this booklet. However, some care should be taken when using the dispersal and dilution formulae. The section of this chapter on examples of dispersal systems is lavishly illustrated, perhaps at the expense of text (11 pages of photographs, 2 pages of text).

Appendix A deals very briefly and uncritically with the measurement of face air velocities by referring to published work and manufacturers of anemometers without comment.

Overall, however, this is a readable booklet whose practical approach to fume cupboard design, backed up by a comprehensive reference list, should be useful to anyone taking a critical look at an existing fume cupboard system or considering the installation of a new system.

Handbook of Ventilation for Contaminant Control. 1976. H.J.McDermott. Ann Arbor Science Publishers Inc. ISBN 0-250-40139-8 368 pages.

The opening chapter explains the requirements of the OSHA standards relating to ventilation and gives guidelines as to how these standards can be met by those responsible for their implementation. Subsequent chapters cover subjects from the steps to be followed in the assessment of hazards, through the basics of local exhaust ventilation, to the design of an installation. The section on fans is well written and gives a good background to the subject; however the section on hood design is brief and outdated. The book includes a chapter on a topic which is usually neglected, namely the economics of ventilation systems and ways in which costs can be minimised whilst still providing protection to health. Useful chapters on system testing and problem solving are also included.

The book has not been updated since first publication and certain areas (eg OSHA regulations and hood design) shows signs of their age. However it does contain chapters on important topics which receive little attention elsewhere and these make it a worthwhile reference book.

Clearing the Air - A Guide to Controlling Dust and Fume Hazards in the Rubber Industry. 1982. Rubber and Plastics Research Association (RAPRA) (See Appendix 4), 79 pages.

This small book was prepared by a tripartite committee of employer, employee and HSE representatives. It covers the making of rubber products; how to approach control and the need for a strategy; a chapter on monitoring; a run through a variety of solutions to dust and fume problems starting with non-ventilation methods and a chapter on examining workers health. The Appendices cover safety policies, safety representative organisation, dust suppressed chemicals, monitoring for rubber fume, how to choose an expert and where to go for further information.

As a simple introduction to air contaminant control this book succeeds and its approach is applicable across many industries. It does try to cover too much in too small a space but the basics of good design and the systematic approach to controlling air contaminants are there. Also it is readable and accessible for the non-technical reader. This book is a good starting point for safety representatives, safety officers, managers and others who become interested in the field.

12.4 Publications Produced by Specific Organisations

BRITISH STANDARDS INSTITUTION (BSI)

BS 848 — Fans for general purpose (Part 1: 1980. Methods of testing performance. Part 2: 1966. Fan noise testing).

BS 1339 — 1965 (1981) Definitions formulae and constants relating to the humidity of air.

BS 3456 — (Section 2.2.3: 1971. Cooker ventilating hoods; Section 2.29: 1971. Ventilating Fans).

BS 4773 — 1971. Methods for testing and rating air terminal devices for air distribution systems.

BS 4934 — 1973. Safety requirements for electric fans and regulators.

BS 5601 — Part 1: 1978. Ventilation

BS 5643 — 1984. Glossary of refrigeration, heating, ventilation and air conditioning terms.

BS 5720 — 1979. Code of practice for mechanical ventilation and air conditioning in buildings.

BS 5925 — 1980. Code of practice for design of buildings: ventilating principles and designing for natural ventilation.

BS 4718 — 1971. Methods of test for silencers for air distribution systems.

BS 6540 — 1985. Air filters used in air conditioning and general ventilation. (Part 1 - methods of test for atmospheric dust spot efficiency and synthetic dust weight arrestance).

BS 5295 — 1976. Environmental cleanliness in enclosed spaces (Parts 1, 2 & 3). Specification for controlled environment clean rooms, work stations and clean air devices).

CP 413 — 1973. Ducts for building services.

CP 1011 — 1961. Maintenance of electric motor control gear.

CP 1015 — 1967. Electrical equipment of industrial machines.

BS 3928 — 1969. Methods for sodium flame test for air-filters.

BS 2831 — 1978. Methods of test for air-filters used in air-conditioning and general ventilation.

Annotated Bibliography

BS 5726 1979. Specification for microbiological safety cabinets.

DD 80 1982. Laboratory fume cupboards (parts 1-3).

British Hydromechanics Research Association (BHRA)

INTERNAL FLOW SYSTEMS, 1978, MILLER, D.S., BRITISH HYDROMECHANICS RESEARCH ASSOCIATION. ISBN 0-900983-78-7, 290 PAGES.

This is a book of fundamentals for energy losses in pipe and duct systems. In the first part (about 120 pages) friction and turbulence losses are explained and methods of pressure loss quantification are provided. The phenomenon of cavitation in various pipe configurations is also covered. In Part 2 friction loss factors for every conceivable configuration of fluid path are given including details of the interaction of flows between two causes of energy loss in close proximity for example, combined bends. This book is the source from which friction factors quoted elsewhere are drawn and is the source to which the ductwork designer will turn in difficult or unusual cases.

Chartered Institute of Building Service Engineers (CIBSE)

The Guide published by the Chartered Institution of Building Services Engineers (CIBSE) is the standard work of reference for UK heating and ventilation engineers. (Note: The Institution has changed its name twice in recent years, and the Guide has also been known as the CIBS Guide and the IHVE Guide. Sections of the Guide appear under the name which was current at the time of their publication). The objective of the Guide is to provide comprehensive information on the design, installation and operation of building services systems, and it tends to concentrate on the indoor thermal environment. Nevertheless, it does provide useful data on ventilation, and is therefore of interest to the practising occupational hygienist as a general source of reference. The Guide is published as a series of A4 booklets, varying in length from about 12 to 100 pages, divided into 3 groups as follows:

A - Design data, concerned with basic information such as recommended temperature standards, the thermal response of buildings and meteorological data.

B - Installation and equipment data, containing sections on ventilation requirements and systems, fire protection, operating costs etc.

C - Reference data, giving tabulated information on the thermal properties of air, water and steam, heat transfer coefficients, thermal properties of fuels etc.

Individual sections of the Guide are revised from time to time, although in recent years the updating process seems to have slowed down considerably. For the occupational hygienist, the potentially most useful sections of the Guide are:

Section A1 - Environmental Criteria for Design. 20 pages. Published 1978

This section provides the basic physical criteria for control of the indoor environment, dealing with thermal comfort, ventilation, lighting and noise. It includes basic information on ventilation needs to control exhaled CO_2, body odours and tobacco smoke, and recommends fresh air supply flowrates for a variety of types of occupied spaces (eg factories, board rooms, restaurant kitchens, conference rooms). No mention is made, however, of ventilation to airborne process contamination. On the thermal side, the emphasis is on achieving themal comfort rather than avoiding thermal stress.

Section A2 - Weather and Solar Data. 95 pages. Published 1982

The main use of this section to the practising occupational hygienist is as a data source for external wind and weather conditions when assessing requirements for ventilation and/or heating to provide an acceptable indoor working environment. It is likely that the data on wind speed and direction will be of assistance when making estimates of natural ventilation rates (using for example, the procedure in BS 5925), see Chapter 9.

Section B2 - Ventilation and Air Conditioning (Requirements). 35 pages. Published 1976

This section contains a lot of useful information on systems for both general ventilation and control of hazardous substances in particular industries, but it is by no means comprehensive, and is fast becoming out of date. A summary of the 1974 ACGIH TLV list is printed, under the heading "Maximum allowable concentrations of gases and vapour", for example, and the data on mechanical ventilation rates for various hospital departments are derived from sources that were published in the early 1960's. There is therefore a need for a thorough revision of this section if it is to be considered relevant to the workplace control of substances hazardous to health.

Section B3 - Ventilation and Air Conditioning (Systems and Equipment). 40 pages. Published 1977

Room air distribution and LEV hood design are given several pages in this Section of the Guide, but for both these topics there has been a considerable broadening of knowledge since 1977 and there is currently renewed interest in hood design and performance. This Section is therefore in need of extensive review and updating, in common with Section B2. As this is an active area of interest among environmental engineers, occupational hygienists and others, the information presented in this Section needs to be reviewed on a regular basis. Other topics covered include duct sizing procedures and air conditioning design methods. Descriptive details and operating characteristics are also given for the major components of ventilation and air conditioning systems.

B16 - Miscellaneous Equipment

This section deals with system components which link together major iterns of plant to form a building services system. It is concerned with piping, ducting, pumps, dampers, steam traps and the like. It makes reference to British Standards and industry specifications where appropriate. A seven page sub-section on ductwork design, standard sizes, support spacings and dampers is of particular relevance to occupational hygienists.

B18 - Owning and Operating Costs. 23 pages. Published 1977

The first three-quarters of this Section deals with economic evaluation procedures (including discounted cash flow estimations) and with methods for estimating energy running costs for heating and air conditioning systems. It is only towards the end that the money cost of energy is discussed and this treatment of the subject usefully extends the relevance of the section, as it is much less prone to becoming obsolete as energy prices rise. A final chapter on miscellaneous costs draws attention to items that will often be hidden in overall budgets and accounts, but yet form part of the true costs of running a system, including the costs of maintenance tools, cleaning materials and breakdown insurance cover. Although this Section does not give a great deal of information that is immediately useful to the practising occupational hygienist, it provides an insight into a neglected area. Prudent study of this subject may well be repaid if cost-consciousness turns out to be an essential element of COSHH - consciousness.

C4 - Flow of Fluids in Pipes and Ducts

Contains basic reference data on pressure drop characteristics of straight lengths of ducting and fittings of various types, for design purposes.

C7 - Units and Miscellaneous Data

Every engineering reference work should have readily available a section on units of measurements, conversion factors, preferred multiples etc. This section presents data in all these areas in a straight forward manner, and remains fairly well up-to-date, despite having been published in 1974.

Annotated Bibliography

HEALTH AND SAFETY EXECUTIVE (HSE)

DUST EXTRACTION SYSTEMS IN THE CERAMICS INDUSTRY. HMSO. 1975, 23PP. ISBN 0-11-880348-4 .

This is a report of the recommendations prepared by the Joint Standing Committee for the Pottery and Allied Trades. The first four sections cover the application of exhaust ventilation, ducting arrangement, collection and disposal of dust, and maintenance and testing of dust extraction plant. These sections are brief, generalised and add little or nothing. The fifth section on Suggested Engineering Standards is based on work of the Ceramic Engineering Group, engineers from some of the leading firms in the pottery industry. This section has useful information on duct work and dust collectors. The final section contains recommended designs of exhaust hoods/fettling benches, most of which have been developed or evaluated by the BCRA.

FOUNDRY DUST CONTROL: FETTLING BENCHES AND SMALL ADJUSTABLE HOODS. HMSO. 1975. 24PP . ISBN 0-11-361077.

This is the second report of a sub-committee of the Joint Standing Committee on Health, Safety and Welfare in Foundries and is concerned with particular applications of the principles of local exhaust ventilation to some types of equipment. Five different types of fettling benches are described with and without partial or full enclosure and extraction through the working surface with or without rear or front slots. Marked differences in the performances were found and it was considered that benches with full enclosure or enclosure approximating to this standard provided the best control. However it is strongly recommended that wherever practicable, mechanical cleaning should precede hand fettling.

Small adjustable hoods for the control of dust produced by the use of hand-held power-driven abrasive wheels on large castings are considered. Because of the dynamic nature of the grinding operation such hoods were found never to control the whole of the dust cloud generated. Mechanical maintenance of the system was not easy and the system was not recommended for general use in normal foundry conditions.

PRINCIPLES OF LOCAL EXHAUST VENTILATION. HMSO. 1975, 87pp. ISBN 0-11-361074-2 (OUT OF PRINT).

This is the first report of a sub-committee of the Joint Standing Committee on Health,Safety and Welfare in Foundries and deals with the fundamental concepts of local exhaust ventilation. The objective was to make data available to engineers and others concerned with the control of dust and fume, in a brief, convenient form so as to allow the right judgements about proposed local exhaust systems to be made. The first part of the report examines aspects of dust and fume which are relevant to the design and use of an LEV plant. The second part is concerned with purely engineering aspects of LEV: hoods, ductwork design, fans, cyclones, filters, commissioning and maintenance. Although some of the information is now out of date, it remains a useful guide. Also included in the report is an appendix on the dust lamp and its use.

FLAME ARRESTERS AND EXPLOSION RELIEFS, HMSO, HSE, HEALTH AND SAFETY SERIES BOOKLET HS(G) 11, 1980, ISBN 0 -11 -883258 -1.

This series of booklets is intended to provide guidance on the practical applications of regulations made under the Health and Safety at Work Act 1974.

The first part of the booklet presents technical information on flame arresters and puts forward recommendations for industrial users so that the installation of flame arresters in industrial plant and equipment can be on a safe and economic basis. It describes the functions and principles involved in specifying different types of flame arrester for use in industrial pipe and duct systems.

The second part of the guide deals with explosion reliefs for ducts and elongated vessels where the length/diameter is greater than or equal to 6 and the diameter does not exceed 2 ft 6 in (Imperial units are used exclusively throughout). Basic design formulae are given. In the light of current knowledge, paragraph 114 gives some "unfortunate" advice on the use and testing of asbestos millboard as a bursting material for vent closures, and this will be amended in any future reprint.

INSTITUTE OF CHEMICAL ENGINEERS (IChemE)

A GUIDE TO DUST EXPLOSION PREVENTION AND PROTECTION. PART 1 - VENTING. C. SCHOFIELD, INSTITUTION OF CHEMICAL ENGINEERS, RUGBY, 1985, PAPERBACK, 96 PAGES.*

The design of explosion relief vents is not a unique process, particularly when the explosible medium is a suspension of combustible dust or powder. A conference on the topic organised by the Fire Research Station in 1981 highlighted the multiplicity of approaches. Clive Schofield has drawn together threads from the UK (using *inter alia*, Fire Research Station work) and Europe (principally the work of Bartknecht and Eckhoff) to produce a guide on explosion venting covering the range of relevant available design methods. The user of this guide will, however, need to read the document completely and in careful detail before appreciating all the nuances.

All the necessary information is included: dust properties; calculation of vent area; design principles for closures; and application of particular plant.

The information is already available in other books (for example Palmer, Field, Bartknecht) but it has been brought together here in a form which will be attractive to the specialist designer (PFT).

VENTING GAS AND DUST EXPLOSIONS - A REVIEW. G LUNN, INSTITUTION OF CHEMICAL ENGINEERS, RUGBY, 1985, PAPERBACK, 144 PAGES.*

In a second, companion monograph, Geoff Lunn has done a service to those working in the field of explosion protection and to those wishing for more detailed information on explosion (gas and dust) venting. There is much information on the available literature (up to 1983) with detailed analysis, comment, comparison and recommendations for design methods.

Research areas which might profitably receive attention are listed. Some of these are now the subject of a research initiative by the British Materials Handling Board (PFT).

A USER GUIDE TO DUST AND FUME CONTROL (2nd EDITION) INSTITUTE OF CHEMICAL ENGINEERS, LONDON, 1985, PAPERBACK, 140 PAGES , (ISBN 0852951809)*

This short book plays to the strengths of the chemical engineer, thus about 60% of the text is devoted to air cleaning and fans. These areas are covered clearly and concisely, obviously written by people with direct practical experience.

Unfortunately, other areas vital to the effective control of exposure to dust and fumes are hardly mentioned or are given short shrift: Health and Safety requirements are covered in three pages; Process and Material Changes are covered in three more, and Air Sampling, the essential final arbiter of success, is accorded half a page and one dubiously relevant reference. Strangely, given the writers' background, the prevention of fire and explosion is covered in passing and the two recent Institute publications on the subject are not even referenced! Given that this is a second edition of this book the "Reference and Suggestions for Further Reading" is sadly out-of-date and incomplete. For instance, Threshold Limit Values for 1978 are cited, there are almost no references to work on occupational hygiene, the reference to air flow measurement omits CIBS publications, and the 15th Edition of ACGIH's "Industrial Ventilation" manual is listed when the 18th Edition came out in 1984. The hood design data are taken straight from the latter publication (without credit) and are out-of-date. The work of Fletcher, which supercedes some of the A.C.G.I.H. formulae, is not

* Reviews taken from "Health and Safety at Work", October 1985 and April 1986, with per mission.

mentioned in the main text and though an obscure conference paper is cited none of his papers in the Annals of Occupational Hygiene are listed.

There is much use in this book but the "user" should be aware that is offers only partial solutions.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH (NIOSH), USA. *(ADDRESS - SEE APPENDIX A)*

All NIOSH publications can be purchased in the UK via Microinfo Ltd (see Appendix 4).

NOISE CODE No	TITLE
74-117	The Industrial Environment: Its Evaluation and Control
75-107	Ventilation Requirements for Grinding, Buffing and Polishing Operations
75-108	Development of Design Criteria for Exhaust Systems for Open Surface Tanks
76-154	Urethane Foams - Good Practices for Employees' Health and Safety
76-162	Recommended Industrial Ventilation Guidelines
76-186	Recirculation of Exhaust Air
78-109	An Evaluation of Cotton Dust Control Systems
78-124	Recommended Approach to Recirculation of Exhaust Air
78-141	The Recirculation of Exhaust Air ... Symposium Proceedings
78-159	Engineering Control Technology Assessment for the Plastics and Resins Industry
79-114	An Evaluation of Occupational Health Hazard Control Technology for the Foundry Industry
79-125	Assessment of Selected Control Technology Techniques for Welding Fumes
79-143A	Validation of a Recommended Approach to Recirculation of Industrial Exhaust Air - Vol I (Spring Grinding, Chrome Plating, Dry Cleaning, Welding, and Vapour Degreasing Operations)
79-143B	Validation of a Recommended Approach to Recirculation of Industrial Exhaust Air - Vol II (Lead Battery, Woodworking, Metal Grinding, and Enamel Blending Operations)
80-143	Control Technology Assessment: The Secondary Nonferrous Smelting Industry

Annotated Bibliography

81-113 Used	Evaluation of Air Cleaning and Monitoring Equipment in Recirculation Systems
81-121	An Evaluation of Engineering Control Technology for Spray Painting
85-116	Recommendations for Control of Occupational Safety and Health Hazards ... Foundries

WARREN SPRINGS LABORATORY (W.S.L.)

Drs Schofield and Higman have written various papers based on the work of the "Dust and Materials Handling" project. Also various reports, listed in the book on Advance Design of Ventilation Systems by Goodfellow (see Section 12.3) may be obtainable. The papers and reports are listed below.

Reports:

1978	Higman, R.W. Bag filtration. Paper to Particle Workshop. University of Loughborough
1979	W.S.L. authors. Dust and fume control. W.S.L. Industrial Seminars. 1979-81 (6 in total)
1980 (Jan)	Higman, R.W. and Schofield, C. Cyclones and filters. Paper to Seminar G. Powder Europa. Weisbaden
1981 (Oct)	Higman, R.W. The control of dust generation in materials handling operations. Paper to British Rubber Manufacturers' Assoc. Ventilation Symposium, Birmingham
1981 (June)	Higman, R.W. Survey of container filling and emptying practice. W.S.L. Report No 3
1981 (Oct)	Higman, R.W. and Schofield, C. Control of dust dispersion by contaminant exhaust. W.S.L. Report No 4
1982 (Feb)	Schofield, C. Ductwork design for dust control. W.S.L. Report No 6
1983 (Apr)	Schofield, C. and Shillito, D. Handling of dusty material in ports - impact, prevention and control (British Materials Handling Board, Berkshire, UK)
1983 (June)	Higman, R.W. and Schofield, C. Air entrainment by falling streams. W.S.L. Report No 13
1983 (June)	Masood, T. The capture of dust by hoods. W.S.L. Report No 13
1984 (March)	Higman, R.W., Schofield, C. and Taylor M. Bulk material dustiness, an important material property - its measurement and control. Paper to 4th Int Environ and Safety Conf, London

1985 (May)	Higman, R.W. and Schofield, C. Dust and materials handling. Industrial awareness seminar 6. (consists of 10 papers) 10th Powder and Bulk Solids Conf/Exhib, Chicago
1985 (July)	Higman, R.W. The hazards of handling fine powders. Lecture to IChemE course "Processing of Cohesive Powders", Univ Bradford
1985 (Oct)	Dustiness testing - a useful tool. Paper to Ventilation '85, First Int Symp on Ventilation for Contaminant Control. Toronto

12.5 MISCELLANEOUS

12.5.1 *FAN APPLICATION GUIDE. 2ND EDITION, 1981. HEATING, VENTILATING AND AIR CONDITIONING MANUFACTURERS 'ASSOCIATION LTD, HEVAN (SEE APPENDIX 4). 48 PAGES.*

For the practitioner not particularly interested in the intricacies of fan design (see FANS by Osborne) this publication is a useful practical guide. It runs through fan types, where and how to measure pressure, fan laws and system resistance, essential points to watch for in system design and installation, noise and vibration, electric motors and troubleshooting. The points are clearly explained and well illustrated.

FANS. 2ND EDITION, 1977. W.C. OSBORNE, PERGAMON PRESS. ISBN 0-08-021726-5. 228 PAGES.

This book starts with a chapter on fluid mechanics as applied to aerofoils and then goes on to describe fans and fan laws, fan operation, vibration and noise and the design of fans. It contains a wealth of theoretical and empirical detail and its main audience is probably fan designers and students of fan engineering.

12.5.2 *AIR FILTRATION, 1973. C.N. DAVIES. ACADEMIC PRESS INC (LONDON) LTD. ISBN: 0-12-205660-4. 171 PAGES.*

The author of this book is a world authority on the behaviour of aerosols and has a good sense of history. The introductory two chapters review use and development of filters which have been used, or at least their use has been recorded, since the time of Pliny. There then follows chapters on early theories of filtration, resistance of filters, modern filtration concepts and electrical force in filters, membrane and rotary impaction filters, pore and adhesion theory and clogging.

The contents of this book are exhaustive and concerned with the theoretical and experimental aspects of the subject. In the forward H.L. Green points out that this is not an easy subject, ..."since the theory demands more than a passing acquaintance with fluid dynamics and there are many mathematical refinements whose significance may be difficult to appreciate". This is a book for the specialist reader.

DUST CONTROL AND AIR CLEANING, 1974, R.G. DORMAN (EDS). PERGAMON. LONDON. ISBN 0-08-016750-0. 615 PAGES

The editor and four other authors have written this book for engineers and engineering students. It covers definitions of aerosols and their various health effects; aerosol physics, the theory and practice; air cleaning in some detail and depth; filter testing; specific applications of air cleaners (Atomic industries, clean rooms and mixing) with a final chapter on air pollution control.

The book is readable and offers practical advice supported by theory particularly when it comes to air cleaning. It deals solely with aerosols and does not touch on gas or vapour control. Also, it is somewhat dated. Most modern references hail from the 1960's and, for example, considerable detail is given on sampling methods which rely upon particle counting whereas most methods are based on gravimetric analysis nowadays. Despite these drawbacks there is still much practical information of use in this book.

12.5.3 *DUST EXPLOSIONS AND FIRES, 1973, K.N. PALMER. CHAPMAN HALL. LONDON. 396 PAGES.*

The author's is an authority in the field with years of experimental and theoretical work at the Fire Research Station. The book is comprehensive and covers the historical development of our knowledge of dust explosions, explosibility tests, propagation of dust flames, sources of ignition and explosion protection, dust fires and the application of theory and experiment to industrial processes. This is the authoritative book in the field.

12.5.4 *RESPIRATORY PROTECTIVE EQUIPMENT*

British Standards

BS 4275	1974. The selection, use and maintenance of respiratory protective equipment.
BS 2091	1969. Respirators for protection against harmful dusts, gases and agricultural chemicals.
BS 4555	1970. High efficiency dust respirators.
BS 4558	1970. Positive pressure, powered dust respirators.
BS 4771	1971. Positive pressure, powered dust hoods and blouses.
BS 4667	1974. Breathing apparatus.

Approved Lists

Health and Safety Executive - Certificate of Approval (Respiratory Protective Equipment). F2486. (List of approved RPE issued each year). HMSO.

Health and Safety Executive - Chemical Works Regulations 1922, Certificate o Approval (Canister Gas Respirators). F2505 (Approved list issued each year). HMSO.

Books

National Institute of Occupational Safety and Health (NIOSH), 1976. A guide to industrial respiratory protection 76-189 (available via Microinfo or US Government Printing Office, see Appendix 4).

Ballantyne, B. and Schwabe, P.H., 1981, Respiratory Protection - principles and application. Chapman and Hall Ltd. ISBN 0-41-222750-9.

Douglas, D.D.,1978, Respiratory Protective Devices, pp 993-1058. In, Clayton G.D. and Clayton, F.E. (Eds) 3rd edition, Patty's Industrial Hygiene and Toxicology, Volume 1, ISBN 0-471-16046-6

<u>Suppliers</u>

Safety Equipment Distributors' Association, Gateway House, 50 High Street, Birmingham B4 7SY (021-643 6271)

Protective Clothing Distributors' Association, Shield House, 5 Lysander Close, Clifton Moor Gate, York, YO3 8XB (0904-646 381)

<u>Manufacturers</u>

Reference book of protective equipment. Industrial Safety Manufacturers' Association. Available from 69 Cannon Street, London, EC4N 5AB (01-248 4444).

12.6 References in Hygiene Journals

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CINKOTAI, F.F. (1983) Control of Airborne Dust in Cotton Spinning Mills. Vol 26. pp235

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12.7 Computerised Databases

The literature on air contaminant control including exhaust ventilation is fragmented and spread throughout the scientific journals. There is no single database which covers air contaminant control but by using several identifiable ones most of the potential English language sources can be covered. Each database has a different key word and searching format. Trying to capture all the relevant references without picking up too much irrelevant material is a skill (eg simply using the word "ventilation" may well throw up a host of references concerning lung function!) Anyone contemplating a search, especially if it is across several databases, would be well advised to take advice from a librarian or information scientist. There is also considerable overlap between databases and some only go back a relatively few years. Your adviser may be able to select the best candidate but often you only find out which are the best for your needs after completing a number of searches.

Airbase

This database is produced by the Air Infiltration Centre (AIC), Old Bracknell Lane West, Bracknell, Berkshire, RG12 4AH, (0344-53123). (The database is mainly concerned with air infiltration studies, indoor air pollution and energy conservation. For those concerned with thermal comfort, general ventilation and the use of tracer techniques this database will be particularly useful).

CIS

The CIS database is now available in English from:

International Occupational Safety and Health Information Centre, ILO, CH 1211, Geneve 22, Suisse. (22) 996740. Telex 22271 BIT CH.

(This database is the computer based version of the longstanding bibliographic reference service that the International Labour Office has run for many years. It should contain many references on air contaminant control and will have wide international coverage).

Compendex-4

Supplier - Engineering Information
345 East 47th Street
New York
NY 10117
USA

(212) 705 7600

(A large engineering database covering the full range of engineering bases subjects. Available via a number of host organisations).

EMBASE (Excepta Medica)

Origin: Elsevier Science Publishers BV
Molenwerf 1
1014 AG Amsterdam
The Netherlands

(020) 5803 535

(This database is mainly concerned with the medical and toxicological literature. However it does also cover material on the control of health hazards some of which will be concerned with air contaminant control. It is available via a number of hosts).

HSE Line

The database is owned by the Health and Safety Executive. It is available via:

Department of Trade and Industry
IRS -DIALTECH
Room 392 Ashdown House
123 Victoria Street
LONDON
SW1E 6RB

(01-212 5638 or 01-212 8825)

Pergamon Infoline
12 Vandy Street
LONDON
EC2A 2DE

(01-377 4650)

Annotated Bibliography

Prestel, Prestel Unit
HSE
Library and Information Services
Room 161
Baynards House
1 Chepstow Place
Westbourne Grove
LONDON
W2 4TF

(01-229 3456)

(Since 1977 HSE has stored reference material centrally in computer retrievable form. In December 1981 this database was made available to the public. By February 1986 it contained 80,000 references and 12,000 additional references are added each year. This database will contain a fair number of relevant references on air contaminant control but certainly not all. The journals abstracted are limited in number and the coverage is patchy. It is worth consulting in conjunction with other sources such as CIS and NIOSH TIC).

ISMEC-10

Supplier - Cambridge Scientific Abstracts
5161 River Road
Washington DC
200 16
USA

(800) 038 8076

(A database covering mechanical engineering literature. It will overlap with Compendex-4. It is available via a number of hosts).

Occupational Safety and Health (NIOSH)

Technical Information Branch
National Institute of Occupational Safety and Health
4676 Columbia Parkway
Cincinnati
OHIO 45226

(513) 684 8326

(This database is produced by NIOSH and obtainable via DIALOG. It dates back to 1973 but contains many articles dating back to the 19th century. It is a large and comprehensive database).

APPENDIX 1 - CASE STUDIES IN AIR CONTAMINANT CONTROL

1.0 Introduction

Although it is possible to design a local exhaust ventilation system to extract a specified volume of air, estimating the effectiveness of such a system in terms of its effect on personal exposure to airborne contaminants is more problematic. This is one of the reasons that the designer usually relies upon the standard designs outlined in publications such as the ACGIH "Industrial Ventilation" manual. While very valuable the design guidance given in such publications is of limited usefulness for various reasons including:

(i) Solutions other than LEV are not considered.

(ii) Little guidance on factors to consider in design are provided - examples are very general.

(iii) There is no estimate of costs - either capital or recurrent.

(iv) The work referred to is mainly US in origin.

The practitioner requires more information including some feel for the design method employed and the background as to why a particular approach was chosen. A more detailed and informative source is required.

2.0 The Case Study Approach

Designers or engineers require examples of the various approaches which can be taken to control contaminants produced by a certain process. Particularly useful is information on costs, effectiveness and reliability. Case studies of success and failure could fulfil this need and have been used in the past. One of the members of the Ventilation Working Group of the BOHS (Mr J. Folwell) used such an approach in the asbestos industry in the 1950s. More recently the Health and Safety Executive have published "100 Practical Applications of Noise Reduction Methods" and although those case studies are concerned with noise, the approach we propose is analogous.

Several benefits flow from the development of Case Studies including:

(i) They preserve the lessons learnt and the experience gained in the past in an accessible and readily available form.

(ii) In some cases they might suggest cheaper non-ventilation methods of control for the user who might not otherwise have considered this option.

(iii) They could stimulate the translation of successful solutions to similar problems from one industry to another.

(iv) They allow some estimate of the likely cost of control, both capital and recurrent, to be made.

(v) They could lay the basis of a realistic dialogue between management and workforce in which practical options are discussed.

(vi) In the long term, with feedback, the system would allow the most reliable and cost-effective solutions to be selected.

3.0 Protocol for Preparing a Case Study

3.1 Introduction

Please use the following headings and notes as a basis for case study preparation. The protocol is written as guidance and IF CERTAIN ITEMS OF INFORMATION ARE NOT AVAILABLE THIS DOES NOT NECESSARILY DETRACT FROM THE VALUE OF THE CASE STUDY. Please indicate where information can be gathered that is not available at present. The assumption is made that most problems will be concerned with airborne contaminants but on occasions, problems associated with other routes of entry may make the basis of a Case Study.

3.2 Abstract

Once the Case Study is completed please prepare a summary of the main points in less than two hundred words.

3.3 The Process

Give a short description of the process(es), the machinery involved, the work layout, the number of people and work stations and the approximate dimensions of the area in question. The type(s) of contaminant(s), rate of application/use, the scale of the problem and the magnitude of exposure should also be supplied where data are available. Other possibly significant routes of exposure apart from inhalation should be identified.

3.4 Selection of Control Solution

Give a short description of the way in which the problem was analysed and how the particular control solution was selected from the various alternatives. Wherever possible an attempt should be made to identify the job categories of the people involved in discussions or decision making, eg maintenance works engineer, local ventilation engineering contractor, occupational hygienist, safety officer, work people from the area.

3.5 Design Procedure and Description of Control Solution

Explain how the control solution was developed to take into account factors such as:

The work method of the operators
The size and mobility of the source(s)
The velocity and rate of evolution of the contaminant

The motion of the source or the air motion induced by it, and
Whether the process was intermittent or continuous.

Indicate whether the design procedure involved a mock-up stage or what other methods were used to validate the design. Describe the control solution including detail with sketches, line diagrams, or photographs of the essential features. The information should include where possible appropriate design values for hood face velocities, volumetric flow rates, target capture velocities, transport velocities, and air cleaning methods.

3.6 Degree of Success

A statement should be made about the effectiveness or otherwise of the whole control measure or parts of the control measure, including if possible results of measurements of airborne contaminant levels achieved before and after operation of the control measures. Alternatively a visual assessment of control success could be made supplemented by the use of a dust lamp or other qualitative method of assessment where appropriate. Indication should be given of physical parameters which differed from design values as set out in section 3.3 above, eg air velocity at point of origin of contaminants. Reasons should be advanced for failure of the system if not adequate to control exposure or emission below target levels.

3.7 Supplementary Points

(i) Status of control solution

Indicate whether the solution described is experimental, in use on a pilot scale, or tried and tested and used routinely throughout the site or organisation.

(ii) Costs and Benefits

Describe what benefits accrued, eg improved production, reduced loss or increased recovery of product, cost savings - capital and consumable items, improved industrial relations.

A brief statement of the probable capital and running costs of the control measures with an indication of the year to which the costs relate, eg capital costs, (£10,000), (1980). Wherever possible an indication should be given of the probable recurrent costs associated with the systems, eg replacement parts, estimated yearly maintenance load in hours. It would also be helpful to indicate the probable pattern of use, eg forty hours per week or continuous three hundred and sixty five days per year and whether the system will beneficially remove waste process heat or whether heat loss caused by extraction systems would have to be made up by the factory heating system.

(iii) Comments

A short summary of the good and bad points of the design should be included from the author of the case study, concentrating on a comparison of the design with other approaches to the same or similar problems.

4.0 Conclusions

Case Studies are not a substitute for fundamental knowledge of ventilation and process control, but are envisaged as a useful supplement. Most of the practical work of the hygienist, while immenesly valuable, does not present itself in a form that can be readily published. Case Studies of success and failure of contaminant control are one way of preserving and publicising the ideas and efforts of the hygiene profession.

5.0. Example of a Case Study prepared using the protocol

Improving the Control of Wood Dust Produced by a Rigid Disc Sanding Machine

5.1 The Process

A range of abrasive cutting machines are used in the woodworking and allied industries for stock removal and finishing operations, including disc sanding machines. The development of motor vehicles involves the production of many full size replicas using wood and glass fibre materials.

Disc sanding machines are much used to produce many of the contours required. A typical machine installation is that shown in Figure A.1 below which illustrates a double disc, Wadkin machine fitted with a pair of narrow gap extraction hoods in addition to the extraction beneath the work table - the latter supplied by the manufacturers.

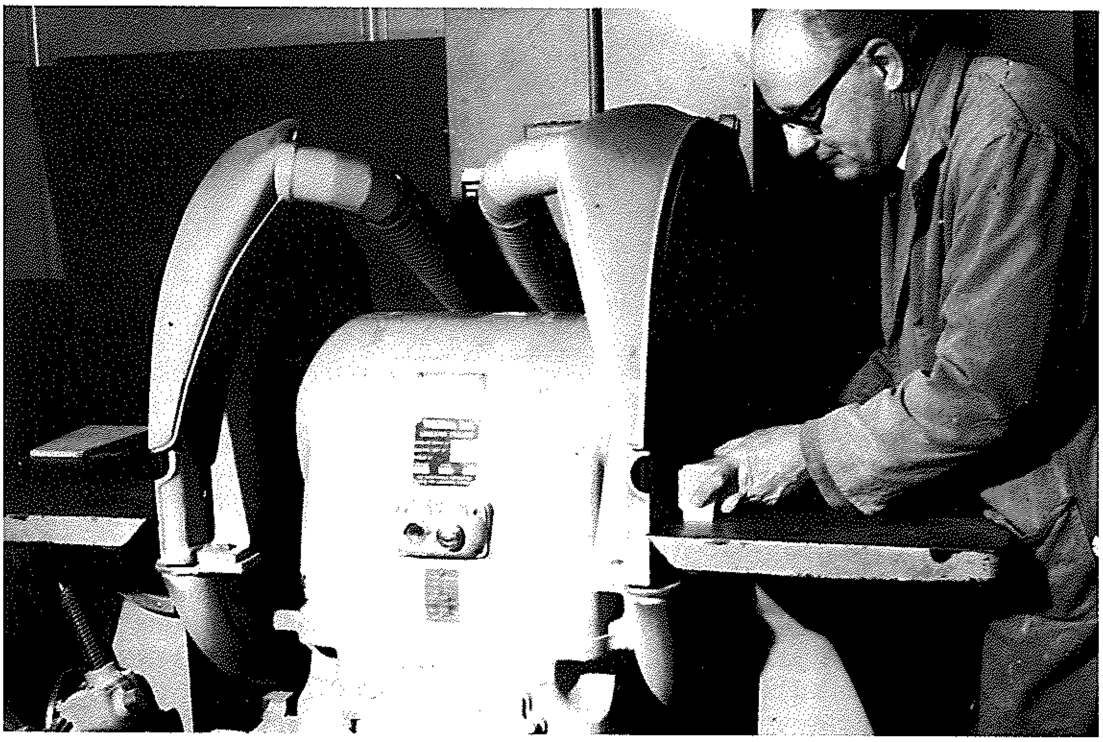

Figure A.1. Wadkin Sanding Machine.

The machine illustrated is fitted with 75 cm diameter abrasive discs rotating at 950 rpm, giving a peripheral speed of some 38 ms^{-1} (7,500 feet min^{-1}). As supplied, some 0.5 $m^3 s^{-1}$ (1,000 cfm) was extracted per disc from below the work table using the shop extractor/dust collector unit.

5.2 Selection of Control Solution and design procedure

Using personal samplers fitted with UKAEA sample heads located about 10 - 14 cm below the clavicle, total mass concentrations of airborne dusts were measured for a typical operation repeated a sufficient number of times to enable a reasonable estimate of concentration to be obtained. Concentrations in the range7.7 to 8.3 mg m^{-3} were recorded. Local atmosphere samples using static samplers located on a nearby work bench were also taken using the sampling heads. Values in the range 4.5 to 4.8 mg m^{-3} were found.

Appendix

The release of dust from the machine was examined with a dust lamp. A cloud of fine dust was seen to issue from the periphery of the disc as shown in Figure A.2.

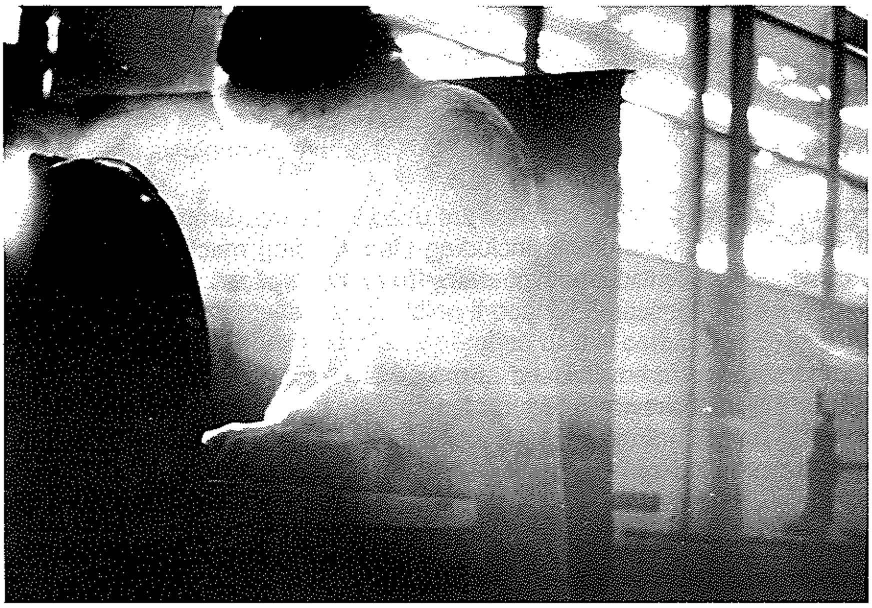

Figure A.2. Dust Emission from the Disc Periphery.

The source of the dust clouds suggested that a secondary hood fitted at the disc periphery would be effective. Conventional hood shapes occupy space in front of the disc. This was not an acceptable arrangement since large wooden fabrications were worked requiring the full height of the exposed disc. A narrow gap hood design was developed and fitted, as shown in the photograph in Figure A.1. This was connected to the existing source of extraction (a central system servicing the workshop) using smooth bore ("HELIFLEX") flexible hose via a Y piece to apportion extraction air volumes between the under-table connection and the secondary hood. The HELIFLEX tubing was selected to minimise duct losses and the sizes used were nominally 75 mm (3 inches) and 150 mm (6 inches) for the secondary and under table connections respectively. The slot dimensions were 16 mm (5/8 inch) wide by 670 mm (26.5 inches) long and typical velocities measured at the face of the slot and inside the connecting hoses were as shown in the diagram, Figure A.3.

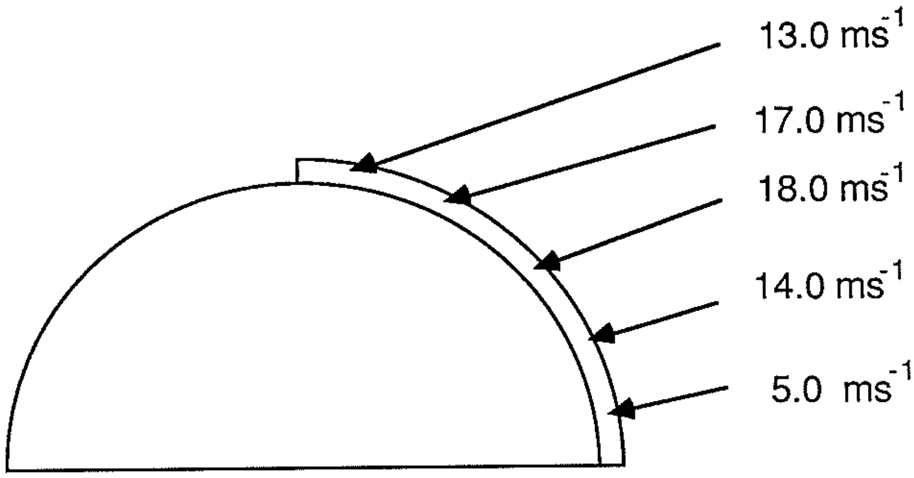

Figure A.3. Typical Air Velocities at Peripheral Slot.

5.3 Degree of Success

Measurements of dust levels after installing the extraction system, personal to the same operative undertaking similar typical work operations, showed that dust levels were now 1.0 - 1.5 mg m^{-3}. For static samplers located on the nearby workbench, levels considerably less than 1.0 mg m^{-3} were found.

A visual check of dust control using the dust lamp indicated a good standard of dust cloud capture, as illustrated in Figure A.4.

Figure A.4. Control of Dust from Sander.

The volumes of air extracted from each branch, the transport velocity and achieved performance are summarised below. However, experiments indicated that good control of dusts was possible with air volumes as low as 0.075 $m^3\ s^{-1}$ (160 cfm) through the secondary hood and a transport velocity of 18 sec^{-1}. The figures below are those measured for an existing system:-

Air volume via undertable duct	0.458 $m^3\ s^{-1}$	(970 cfm)
Air volume for secondary hood	0.116 m^3s^{-1}	(245 cfm)
Total air volume	0.574 m^3s^{-1}	(1215 cfm)
Transport velocity	25 ms^{-1}	(4921 fpm)
Suggested minimum transport velocity	17.8 ms^{-1}	(3500 fpm)
Average centre line velocity - secondary hood	14.4 ms^{-1}	(2842 fpm)

5.4 Status of Control Solutions

The additional hoods were fitted to all rigid disc sanders. They are in regular routine use and have met with the full approval of the operators.

5.5 Comments

An inset slot with a 90^{o} arc was the only hood design which would allow the sanding of large wooden articles. The ACGIH (1982) LEV hood design for the 75 cm disc specified a volumetric flowrate of 1,400 cfm with 2 hoods positioned below the work table. This design, in the authors' opinion, could not control the flow of dusty air shown in Figure A.2. The design outlined in this case study is significantly more efficient and cost effective than the traditional design.

<u>Reference</u>

Industrial Ventilation - a manual of recommended practice (18th Edition) 1984. American Conference of Governmental Industrial Hygienists (ACGIH).

APPENDIX 2 - Smoke Generator Suppliers

1 Smoke Tubes

Draeger Safety Ltd, Sunnyside Road, Chesham, Buckinghamshire, HP5 2AR
(0494) 7744481

MSA (Britain) Ltd, East Shawhead, Costbridge, ML5 4TD, Scotland
(0236) 24966 and
9 Albury Close, Loverock Road, Reading, Berks, RG3 1DZ
(0734) 587 472

Kitawgawa via - Sabre Gas Detection Ltd
Grosvenor House, 36 North Lane, Aldershot, Hampshire, GU12 4DE
(0252) 316611

2 Smoke pellets and canisters

PH Smoke Products Ltd, Glen View Road, Eldwick, Bingley, West Yorkshire, BD16 3EF
(0274) 567 931

Rains Wessex Ltd, Highport, Nr Salisbury, Wiltshire, SP4 6AS
(0722) 20211

Brock's Fireworks Ltd, Industrial Division, Sanquhar, Dumfriesshire, DG4 6JP, Scotland
(06592) 531

3 Smoke Generating Machines

Elven Precision Ltd, Gatwick Road, Crawley, Sussex, RH10 2RQ
(0293) 515 121

Dale Emergency Products Ltd, Faraday House, Eastfield, Scarborough, YO11 3UT
(0723) 584 661

Concept Engineering, 30 White Waltham, Airfield Estate, Maidenhead, Berkshire, SL6 3QQ
(062) 882 5555

APPENDIX 3 - UNITS OF MEASUREMENT

Physical Quantity	SI Units	Previous Unit	Conversion Factor
Length	micrometre µm	micron	1
	micrometre µm	thou	2.54×10^{1}
	metre m	foot	3.048×10^{-1}
Area	square millimetre mm^2	square inch	6.452×10^{2}
	square centimetre cm^2	square inch	6.452
	square metre m^2	square yard	8.361×10^{-1}
Volume	cubic centimetre cm^3	cubic inch	1.639×10^{1}
	cubic decimetre dm^3	pint	5.683×10^{-1}
	cubic decimetre dm^3	US pint	4.732×10^{-1}
	cubic decimetre dm^3	litre	1
	cubic decimetre dm^3	US gallon	3.785
	cubic decimetre dm^3	gallon	4.546
	cubic decimetre dm^3	cubic foot	2.832×10^{1}
Mass	milligram mg	grain	6.480×10^{1}
	gram g	ounce	2.835×10^{1}
	kilogram kg	pound	4.536×10^{-1}
	kilogram kg	hundredweight	5.080×10^{1}
Mass flowrate	gram/second g/s	pound/hour	1.260×10^{-1}
	gram/second g/s	kilogram/hour	2.778×10^{-1}
Volume flowrate	cubic metre/second m^3/s	cubic foot/second	2.832×10^{-2}
	cubic metre/second m^3/s	cubic foot/minute	1.392
Pressure	pascal Pa	millimetre of water	9.807
	pascal Pa	pound/square foot	4.788×10^{1}
	pascal Pa	millimetre of mercury	1.333×10^{2}
	pascal Pa	torr	1.333×10^{2}
	pascal Pa	inch of water (4^oC)	2.491×10^{2}
	kilopascal kPa	inch of mercury	3.386
	kilopascal kPa	pound/square inch	6.895
	kilopascal kPa	kilogram/square centimetre	9.807×10^{1}
	kilopascal kPa	bar	1×10^{2}
Velocity	metre/second m/s	foot/minute	5.080×10^{-3}
	metre/second m/s	foot/second	3.048×10^{-1}
	metre/second m/s	mile/hour	4.470×10^{-1}
Viscosity (Dynamic)	millipascal second mPa s	pound/hour foot	4.134×10^{1}
	pascal second Pa s	poise	1×10^{-1}

Appendix

Viscosity (Kinematic)	square centimetre/ second cm^2s	stokes	1
	square metre/second	square inch/second	6.452
	m^2/s	square foot/minute	1.548×10^{-3}
Energy (including quantity of heat)	microjoule µJ	erg	1×10^{-1}
	joule J	foot pound force	1.356
	joule J	calorie	4.187
	kilojoule kJ	British thermal unit	1.055
	kilojoule kJ	kilocalorie	4.187
	megajoule MJ	horsepower hour	2.685
	gigajoule GJ	therm	1.055×10^{-1}
Power (including heat flow rate)	watt W	British thermal unit/ hour	2.931×10^{-1}
	watt W	kilocalorie/hour	1.163
	watt W	foot pound/second	1.356
	watt W	calorie/second	4.187
	kilowatt kW	metric horsepower	7.355×10^{-1}
	kilowatt kW	horsepower	7.457×10^{-1}
Latent heat	joule/kilogram J/kg	foot pound/pound	2.989
	kilojoule/kilogram kJ/kg	Btu/pound	2.326
	kilojoule/kilogram kJ/kg	kilocalorie/kilogram	4.187
Specific heat	kilojoule/cubic metre kelvin kJ/m^3K	kilocalorie/cubic metre degree celcius	4.187
	metre kelvin kJ/m^3K	Btu/cubic foot degree farenheit	6.707×10^{-1}

NB: Mega (M) = 10^6
Giga (G) = 10^9

APPENDIX 4 - USEFUL ORGANISATIONS AND ADDRESSES

Air contaminant control courses - see: BERBOH, BOHS, IOH(2), also see Hewitt, P.J. (1984) Science Reviews Monograph.

American Conference of Governmental Industrial Hygienists (ACGIH)
6500 Glenway Avenue, Bldg D-7, Cincinnati, Ohio, 45211, USA
(513) 661 7881)

(Publishes the Threshold Limit Values and Biological Exposure Indices annually and produces regular up-dated editions of the "Industrial Ventilation" manual. Membership is limited to "professional personnel in governmental agencies or educational institutions engaged in occupational health activities").

American Industrial Hygiene Association (AIHA)
475 Wolf Ledges Parkway, Akron, Ohio, 44311-1087.
(216) 762 7294

(Various publications on control. Membership "open to persons who are engaged in industrial hygiene activities").

British Examining and Registration Board in Occupational Hygiene (BERBOH)
Secretary: Mr. J. Elphick, BOC Ltd, Great West House, Great West Road, Brentford, Middx, TW8 9DQ.
(051) 373 5631

(Information on examination, registration and courses in occupational hygiene including air contaminant control)

British Lending Library, Boston Spa, Wetherby, West Yorkshire, LS23 7BQ
(0937) 843 434

British Occupational Hygiene Society (BOHS)
1 St Andrew's Place, Regents Park, London, NW1 4LB
(01) 486 4860

(The learned society for those interested or working in occupational hygiene).

British Standards Institution (BSI)
2 Park Street, London, W1A 2BS

Confederation of British Industry (CBI)
103 New Oxford Street, London, WC1A 1DU
(01) 379 7400

Chemical Industries Association (CIA)
Alembic House, 93 Albert Embankment, London, SE1 7TU
(01) 735 3001

Chartered Institute of Building Services (CIBS)
Delta House, 222 Balham High Road, London, SW12 9BS
(01) 675 5211

(Contact Institute for a list of approved courses)

Appendix

Filtration Society, Department of Chemical Engineering, Loughborough University, Leicester, LE11 3TU
(0509) 232 663

Faculty of Occupational Medicine (FOM)
11 St Andrews Place, Regents Park, London, NW1 4LE

Heating and Ventilating Contractors Association (HVCA)
ESCA House, 34 Palace Court, London, W2 4JG
(01) 229 2488

(Membership list available from: HVCA, Publications Department, Old Mansion House, Eamont Bridge, Penrith, Cumbria, CA10 2BX)

Heating, Ventilating and Air Conditioning Manufacturers' Association (HEVAC)
Phoenix House, Middlesex, TW15 9NL

Health and Safety Executive

(i) Occupational Hygiene Section and Medical Division, Stanley Precinct, Bootle, Merseyside, L20 3QZ (051-951 4033)

(ii) Research - RLSD, Occupational Medicine and Hygiene Laboratories, 403 Edgeware Road, London, NW2 6LN (01-450 8911)

(iii) Toxic Substances Division, Baynards House, 1 Chepstow Place, London, NW2 4TF (01-229 3456)

(iv) Field Consultancy Groups (FCG's)

Wales and South West	Brunel House, 2 Fitzalen Road, Cardiff, CF2 1SH (0222-497 772)
London South	3 East Grinstead House, London Road, East Grinstead, West Sussex, RH19 1RR (0342-269 22)
Midlands	McLaren Buildings, 2 Masshouse Circus, Queensway, Birmingham B4 7NP (021-236 5080)
North East	Woodside House, 261 Low Lane, Horseforth, Leeds, LS18 5TW (0532-583 111)
North West	Quay House, Quay Street, Manchester M3 3JB (061-831 7111)
Scotland	Meadowbank House, 153 London Road, Edinburgh, EH8 7AU (031-661 6171)

Institute of Chemical Engineering (IChemE)
Geo E Davis Building, 165-171 Railway Terrace, Rugby, CV21 3HQ, (0788-78214)

Institution of Mechanical Engineers (IMechE)
1 Birdcage Walk, London, SW1H 9JJ (01-222 7899)

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Institute of Occupational Health (IOH)
1 University Road West, PO Box 363, Birmingham, B15 2TT (021-471 3600)

(Short courses on air contaminant control, full-time postgraduate courses in occupational medicine and hygiene from 1988)

Institute of Occupational Hygiene (IOH) 2
Secretary: Dr D K Burns, 7A Park Road, Southport, PR9 9JB (051-951 4511)

(The organisation representing professional hygienists).

Institute of Occupational Safety and Health (IOSH)
222 Uppingham Road, Leicester, LE5 OQG (0533-768 424)

(The organisations for professional safety advisers)

London School of Hygiene and Tropical Medicine
Keppel Street, off Gower Street, London WC1E 7HT (01-636 8636)

(Offers postgraduate courses in occupational hygiene and medicine (full/part time), short courses - some in control; and runs an Information and Advisory Service)

Manchester University, Occupational Hygiene Department, Oxford Road, M13 9PL (061-273 8241)

(Runs a part-time MSc in Occupational Hygiene)

Microinfo Ltd, PO Box 3, Newman Lane, Alton, Hampshire, GU34 2PG (0420-86848)

(This company is the UK distributor for National Technical Information Services (NTIS) of the US Department of Commerce and US Government Printing Office (GPO) publications).

National Institute of Occupational Safety and Health, (NIOSH), (all publications available via Microinfo Ltd, or direct from the Superintendent of Documents, US Government Printing Office, Washington DC, 20402)

Newcastle University, Department of Occupational Health and Hygiene, The Medical School, Framlington Place, Newcastle-upon-Tyne, NE2 4HH (0632-328 511)

(Runs a full-time MSc course in Occupational Hygiene and offer a consultancy service).

Occupational Safety and Health Administration (OSHA)
US Department of Labor, OSHA, Washington DC, 20210, USA

(The US equivalent of the Factory Inspectorate. OSHA produces various manuals on the control of emissions and exposure from a range of processes).

Rubber and Plastics Research Association, (RAPRA), Shawbury, Shrewsbury, Shropshire, SY4 4NR (0939-250 383)

Royal College of Nursing (RCN), 20 Cavendish Square, London, W1M 0AB

Royal Society for the Prevention of Accidents (RoSPA), Cannon House, The Priory Queensway, Birmingham, B4 6BS (021-233 2461)

Society of Occupational Medicine, 11 St Andrews Place, Regent's Park, London, NW1 4LE

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Southbank Polytechnic, Borough Road, London, SE1 0AA (01-928 8989)

(Offers undergraduate courses and consultancy services in occupational hygiene and environmental engineering).

Trade Associations, see: Directory of British Associations, 8th Edition, (1986). Available from: CBD Research Ltd, 154 High Street, Beckenham, Kent, BR3 1EA (01-650 7745)

Trade Union Congress (TUC) (a)
Great Russell Street, London, WC1B 3LS (01-636 4030)

(List of affiliated unions available from TUC, Social Insurance and Welfare Department; publishes various booklets and co-ordinates TUC policy on health and safety).

Trade Union Congress (TUC) (b)
National Education Centre, Crouch End Hill, London N8 (01-341 6161)

(Co-ordinates and prepares material for safety representative training in health and safety).

Warren Springs Laboratory (WSL), Gunnels Wood Road, Stevenage, Hertfordshire, SG1 2BX (0438-313 388)

(Pollution Abatement Division runs the Dust and Materials Handling Project).

No.11, The Disposal of Hazardous Wastes, ISBN 0-905927-26-5, G.E.Chivers, formerly University of Technology, Loughborough, 1983. **Out of print.**

No.10, Education and Training in Occupational Hygiene, ISBN 0-905927-21-4, P.J.Hewitt, University of Bradford, 1983.

No.9, The Performance, Installation, Testing and Limitations of Microbiological Safety Cabinets, ISBN 0-905927-16-8, R.P.Clark, M.R.C., 1983.

No.8, A Guide to the Safe Use of X-ray Diffraction and Spectrometry Equipment, ISBN 0-905927-11-7, E.B.M. Martin, AURPO, 1983.

No.7, Adventitious X Radiation from High Voltage Equipment: Hazards and Precautions, ISBN 0-905927-90-7, E.B.M.Martin, AURPO, 1982. **Out of print.**

No.6, Health Physics Aspects of the Use of Tritium, ISBN 0-905927-85-0, E.B.M.Martin, AURPO, 1982, reprinted 1984.

No.5, Notes on Ionizing Radiations: Quantities, Units, Biological Effects and Permissible Doses, ISBN 0-905927-80-X, D.Hughes, University of Leeds, 1982, reprinted 1983.

No.4, A Literature Survey and Design Study of Fumecupboards and Fume-Dispersal Systems, ISBN 0-905927-50-8, D.Hughes, 1980. **Out of print.**

No.3, The Toxicity of Ozone, ISBN 0-905927-30-3, D.Hughes, 1979.

No.2, Electrical Safety-Interlock Systems, ISBN 0-905927-45-1, D.Hughes, 1978, reprinted with additions 1985.

No.1, Hazards of Occupational Exposure to Ultraviolet Radiation, ISBN 0-905927-15-X, D. Hughes, University of Leeds, 1978, reprinted 1982.

Also available:

HHSC Handbook No. 2, Fumecupboards Revisited, ISBN 0-948237-01-5, 1986, by Dr J.D.Cook, Environmental Safety Group, Harwell Laboratory, and Dr D.Hughes, University of Leeds.

HHSC Handbook No. 1, The Radman Guide to the Ionising Radiations Regulations 1985, ISBN 0-948237-00-7, 1986, by Radman Associates (J.C.Collins, A.M.Freke, R.G.C.Grix, S.K.Stephenson).

Medical Research Council Video Programs (airflow visualization by Schlieren photography):
Biological Containment: Microbiological Safety Cabinets;
Laminar Downflow Cabinets;
The Open-Bench Environment;
Surgeon's Clothing;
The Human Micro-Environment.

Video Training Program: Protection from Ionising Radiation. Five modules: Scientific Background, Units, Principal Hazards, Control of External Radiation, Measuring External Radiation, plus Notes; Commission of the European Communities (Health and Safety Directorate) and University of Sheffield.

Computer Programs in BASIC for Statistics and Occupational Hygiene, twenty-four programs by P.Dewell in translatable BASIC.

continued on inside back cover