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Wilson, A. G.

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CBD 110

Ventilation and Air Quality

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A.G. Wilson

Please note

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Ventilation is the process of supplying or removing air, to or from a space, by either natural or mechanical means in order to maintain an acceptable level of air quality. The air supplied for this purpose usually comes from outside. A distinction can be made between intentional ventilation, which generally implies some form of manual or automatic control, and unintentional ventilation, commonly referred to as air leakage (**CBD 23**).

The need for ventilation usually results from the necessity to control the concentration of contaminants that may produce objectionable odours or toxic effects. Ventilation with untreated outdoor air is commonly used in non-airconditioned buildings to reduce discomfort from over-heating in summer and to prevent excessive relative humidities in winter (**CBD 1**). It is also used to improve occupational environments and to discharge heat, moisture and contaminants arising from industrial processes.

Ventilation needs depend on the occupancy and building use. Ventilation is essential if an adequate environment in buildings is to be provided; it usually involves a significant capital and operating expenditure. It is, therefore, an important consideration in building design.

The Ventilation Process

Ventilation may involve one or both of two processes. Where a source of contamination (including excessive heat and moisture) can be readily isolated, air can be exhausted from its immediate vicinity in such a way that contaminants are captured and directed into the exhaust system before they can diffuse into the occupied space. Good design is required to achieve an effective arrangement. This approach is widely used in industrial applications, an exhaust hood often utilized over cooking ranges being a common example.

Where an entire room is a source of contamination, an exhaust system may be used to isolate it from the rest of the building, as is often done with washrooms. In removing contaminants in this way, provision must be made for an adequate supply of replacement or "make-up" air.

In most situations the sources of contaminants, usually the occupants themselves and their activities, are not readily isolated. The ventilation process then employed is that of dilution. Fresh air is thoroughly mixed with the air in the occupied space and displaces an equal volume of room air, which is at the average room condition when it leaves the space. The net rate at which the contaminant is removed from the space by this process is equal to the quantity of air supplied multiplied by the difference between the concentration of the contaminant in the air leaving the space and that in the supply air. When the concentration of contaminants in the space has reached a constant level, i.e. at steady conditions, the rate of contaminant generation is equal to its rate of removal. If the air in the space is initially fresh, it will take some time after occupancy begins for the concentration of contaminants to approach a steady value because of the dilution effect of the original room air. The length of time will depend upon the room volume, the rate at which the contaminant is produced (usually in proportion to the number of occupants), and the rate of fresh air supply. Because of this time effect, ventilation requirements are sometimes lessened as the volume of space per person increases.

The basic assumption in removing contaminants by the process of dilution is that their complete elimination is not necessary; a person can assimilate small quantities without any objectionable effects, or at least without any permanent injury. This concept is applied broadly in the field of industrial hygiene and is the basis of maximum allowable concentration values for short- and long-time exposures that have been developed for a wide range of contaminants. Application of the dilution principle can be readily illustrated in terms of the control of air contamination resulting from the normal respiratory process.

Control of oxygen and carbon dioxide levels

Fresh outdoor air contains about 21 per cent O_2 and 0.03 per cent CO_2 on a volume basis (the remainder being mainly nitrogen). Significant variations in these proportions can render it unfit for human use. For prolonged exposure a minimum concentration of 16 per cent O_2 and a maximum concentration of 0.5 per cent CO_2 (sometimes extended to 1 ½ per cent) are commonly accepted standards.

A person, when seated, usually inhales about 18 cu ft of air per hr. The exhaled air contains about 16 per cent O_2 and about 4 per cent CO_2. Thus, if only 18 cu ft per hr of fresh air were provided for each person in a continuously occupied space the concentrations of O_2 and CO_2 would approach these levels. Exposure for even a short time to a CO_2 level of 4 per cent would result in a temporary loss of vitality and ability. If, however, ten times this amount of fresh air were provided (180 cu ft per hr or 3 cu ft per minute), the ultimate CO_2 level would be only 0.4 per cent and the O_2 deficiency would be only 0.5 per cent, instead of 5 per cent. Approximately 3 cfm per person may thus be regarded as the minimum rate of supply of outdoor air, or equivalent, that is required to control within accepted limits the concentration of CO_2 arising from respiration of people at rest; only one tenth of this is required to maintain the required levels of O_2. Consumption of O_2 and production of CO_2 increase with activity, and ventilation requirements increase correspondingly. For people who are standing, the values are about 50 per cent higher than for those seated.

In the period immediately following the beginning of occupancy the volume of fresh air in the space has an influence on the time required for the concentration of CO_2 to reach a particular level. For example, with a fresh air supply of 3 cfm per person, the CO_2 level will essentially reach its final steady value in about 3 hr when there is 200 cu ft of space per person, and in about 30 hr when there is 2000 cu ft per person. With no ventilation but with good mixing of the room air and with 200 cu ft of space per person, the CO_2 will reach a level of 0.5 per cent in about 1 hr after the space is occupied.

For many kinds of spaces and occupancies, supplies of outside air in excess of that required to control the effect of respiration on O_2 and CO_2 levels occur through uncontrolled infiltration and exfiltration. In single-family residences, for example, air leakage, with windows closed, usually amounts to at least one complete change of air every 4 hr; assuming 2000 cu ft per person this leakage amounts to about 8 cfm per person. In a crowded classroom, with only 200 cu ft per person, a supply of uncontaminated air equivalent to one air change per hr is required to provide 3 cfm per person and air leakage may not always provide this amount.

Ventilation rates greater than this are required to control odours and, where cooling is not provided, to offset heat gains, which include body heat losses. If windows can be opened, they usually will be opened in response to an awareness of stale air or excessive temperatures before CO_2 levels exceed accepted limits.

CO_2 and other gases, particularly CO and water vapour, are generated in the process of combustion. Where unvented combustion heating devices are used, it is necessary to estimate carefully the volumes of contaminants produced and to ensure that there is sufficient ventilation to keep the concentrations within established limits. This problem arises, for example, with enclosed garages where each automobile generates about 35 cu ft per hr of CO with motor running. Only very low levels of CO can be tolerated; a maximum value of 0.02 per cent is sometimes specified for 8-hr exposure, and 0.1 per cent for short-term occupancy. These call for ventilation rates of about 3000 and 600 cfm respectively for each car which for average conditions, may require fresh air equivalent to 10 or more air changes per hour. This represents a substantial expenditure for energy if the garage is heated in winter.

Control of Odours

The control of odours determines requirements for fresh air, or its equivalent, in most spaces accommodating human activities. The sources are many: body odours and tobacco smoke will usually be the most objectionable in offices or places of assembly; food preparation and garbage are frequent contributors; odours may come from finishing materials and furnishings and even the wetted coils of air conditioning systems as they become dirty; and the outdoor air itself may be an important source in areas where there is serious air pollution.

Although odorants are not the cause of organic disease, obnoxious odours may cause temporary ill effects, including nausea, impaired respiration and insomnia. The nose is extremely sensitive and very small concentrations can be objectionable. Odour perception is greatest on initial exposure and the nose may subsequently become desensitized. It may not, therefore, detect a gradual increase in odour concentration, although the effects may still be felt. Air that seems to be stale or stuffy is usually contaminated with an assortment of odours associated with human activities, and may produce depression rather than the sensation of a specific odour.

Standards of maximum odour concentration for occupied spaces have not yet been developed because of the difficulty of identifying and measuring the various odour producing vapours, and of relating the measurements to human response. Instead, building codes and other design guides currently specify minimum rates of fresh air supply, or equivalent, required for various kinds of occupancies, usually in terms of cubic feet per minute per person, to provide adequate dilution. These values are based on both the results of laboratory studies of the subjective reactions of people and on experience. The rates required are dependent upon the kind of activity and amount of smoking, and vary from 5 to 50 cfm per person; a range of 10 to 30 cfm per person covers the majority of situations. Values are sometimes adjusted for the volume of space per person although this is now regarded as a questionable practice except for transient occupancy; the time after initial occupancy during which the original volume of air in the room influences the concentration levels is reduced as the rate of ventilation increases.

It is necessary to supply fresh air in a manner that will ensure good mixing with the room air. In buildings with mechanical ventilation systems this is accomplished by blending the outdoor air with a larger quantity of air from the building and distributing the mixture to the space (**CBD 106**). The air brought in from outdoors must be heated in winter. In centrally air conditioned buildings, the mixture is processed in the plant to handle the heat and moisture loads of the space (**CBD 109**), the total amount of air that must be circulated being determined by these loads. Typical rates of total air circulation for office air conditioning are 1 to 2 cfm per sq ft of floor area, with about 15 per cent of this being outdoor air. These values vary widely, however, with the type of occupancy and construction. Although not necessarily regarded as good practice, it is not uncommon to reduce the proportion of outdoor air during periods of peak heating or cooling requirements in order to reduce the load on the plant.

Because of the cost of conditioning outdoor air, and because of increasing pollution levels in some areas, the designer may wish to give consideration to the conditioning of indoor air with odour removing equipment as an alternative to ventilation with outdoor air. This can take a number of forms, the one most widely applied to building air conditioning being adsorption by activated charcoal. This material is supplied in pellet form and applied as a bed through which the air stream passes. Performance can be varied through the design of the bed and the selection of the material. When the charcoal has adsorbed its full capacity of odorants, it is usually returned to the manufacturer for regeneration and replaced with fresh charcoal. The design of such a system would normally be based on established requirements for outdoor air. For example, if outdoor air requirements for odour control amount to 20 per cent of the air being circulated, processing all of the circulating indoor air with an odour controlling device that is 20 per cent effective would give comparable results. Outdoor air would, however, normally be required in sufficient quantity to maintain CO_2 levels within acceptable limits. In unusual situations where outdoor air is not available, such as in submarines, the CO_2 levels can be controlled by chemical treatment.

Control of Airborne Particles

A variety of airborne particles, such as dust, smoke, pollens and organisms, are contained in the outdoor air brought in for ventilation while others are brought indoors or generated by the activities of the occupants. Limiting the concentrations of these contaminants is another important aspect of air quality control; it involves primarily the special technology of air cleaning which is beyond the scope of this Digest. The total rate of air circulation determines the rate at which particles are gathered by the air cleaning equipment and is, therefore, a factor in the degree of air cleanliness achieved. Ventilation can be a significant factor in reducing the concentration of fine air-borne particles generated indoors, such as those in tobacco smoke. Control of dusts evolved in industrial processes may be effected with exhaust-hood arrangements.

In hospitals, where the control of infection from airborne sources is of special importance, ventilation is used to provide positive pressures in spaces containing patients prone to infection and negative pressures in spaces containing patients with highly communicable diseases. It is common practice also to circulate a high proportion of outdoor air, up to 100 per cent, in areas such as operating rooms. This results in a particularly high heating and cooling load for ventilation and leads designers to consider the economics of heat recovery devices in the exhaust air stream.

Ventilation and Summer Cooling

In buildings without air conditioning systems, ventilation with outdoor air is utilized in summer to dissipate the internal heat gains and that from solar radiation. In hot weather, inside conditions will be tolerable only if indoor temperatures are not allowed to exceed those outdoors by more than a few degrees. Buildings without air conditioning should, therefore, be designed to minimize heat gains and to provide high rates of ventilation; for example, the equivalent of 30 or more air changes per hour. This can usually best be achieved with large openable window areas arranged for ventilation through the occupied zone. The flow of air past occupants provides an additional measure of relief by increasing convective heat losses.

Commercial and institutional buildings are sometimes designed with air handling systems intended for future air conditioning but which provide only mechanical ventilation initially. Ventilation quantities supplied by this means will almost always be inadequate for the relief of summer heat and unless additional ventilation is available through openable windows, conditions will probably be intolerable on warm days.

Conclusion

Adequate ventilation of occupied spaces with outside air, or its equivalent, is a basic requirement for achieving acceptable environmental conditions within buildings. Unless it is provided, the quality of the environment and the well-being of the occupants will suffer. It is, therefore, an essential element in the design of a building and its services. The components incorporated in buildings for ventilation usually involve some additional capital expenditure; the heating and cooling load represented by outdoor air involves a significant operating expense. In special situations the use of air purifying or heat recovery equipment may provide some economic options. Good design, therefore, requires a knowledge of the factors determining ventilation requirements and the ways in which the purposes of ventilation are achieved.