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HOODS FOR SCIENCE LABORATORIES.

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Detailed discussions are presented dealing with the selection and design of fume hoods for science laboratories. Areas covered include--(1) air flow design, (2) materials properties, (3) location in the laboratory, (4) testing and adjustment, (5) exhaust systems, and (6) hazards of fume discharges. (JT)

Hoods for Science Laboratories

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Architects have been giving vivid testimony to the significance of fume hoods and their associated exhaust equipment by the substantial number of recent science buildings in which they have moved service shafts housing exhaust ducts to the exterior wall as a means of expressing the functional characteristics of this type of building. Architects have been among the pioneers in the use of the chemical fume hood as a safety device in research laboratories and have been instrumental in bringing the technology of this means of environmental control to the present state of development. Nevertheless, after careful review of several hundred science buildings, the Architectural Services Staff of the National Science Foundation has concluded that much needs to be done to achieve wider dissemination and understanding of the basic principles of the fume hood's design and use. The objective of this chapter is to present a brief outline of principles for satisfactory use of fume hoods in science laboratory design, serving as an introduction to the subject for those architects who have not yet had the opportunity to study this important element of science building design.

A fume hood is an exhaust duct terminal, so conceived that it can enclose an experiment. The enclosure has one or more openable sides and is designed so it can transform the suction of the duct into a uniform movement of air across the face of the opening. Hazardous experiments involving toxic chemicals, and those with unpleasant odors, are conducted within the enclosure. The flow of air into the enclosure sweeps the toxic and odoriferous vapors and dusts into the duct to be exhausted out-of-doors, thus protecting the person working in front of the hood and also preventing the toxic and odoriferous materials from passing into the air of the laboratory.

THE IMPORTANCE OF FACE VELOCITY

Satisfactory performance of a fume hood requires that the airflow past the opening into the enclosure occur within minimum and maximum limits, since both are of great importance. They vary somewhat depending upon a number of factors relating to the design of the particular hood, its location in the laboratory and the degree of hazard of the experiments; therefore, the limits must be selected with judgment. The minimum face velocity must be great enough to insure that the direction of air movement at any point in the area of the open face of the hood will always be into the hood. It is desirable that the lowest possible amount of air be exhausted, consistent with safety requirements, because of the economic advantage of reducing losses of heated air in winter and cooled air in summer. Factors influencing the minimum safe face velocity for a particular hood are numerous.

The upper limit of air velocity for a fume hood is related to the aerodynamic flow pattern created by the air stream flowing past the scientist in front of the hood, past the experiment itself and out the exhaust opening. The scientist standing in front of a hood serves as a barrier to the air stream, and when the air velocity reaches a certain point, a low pressure or partial vacuum is created directly in front of him. The low-pressure zone extends into the fume hood increasingly as the face velocity is increased. A velocity can be reached where the low-pressure zone may extend into the area of the fume hood occupied by the experimental apparatus. When this condition is reached, the fumes generated by the experiment will fill the low-pressure zone and may contact the scientist's skin or be inhaled unless he is protected by a portable shield or a horizontally-sliding sash.

Within the two limiting extremes of face velocity the choice of air-flow rate is based on the desire to reduce to a minimum the total flow of air being exhausted and to maintain a safe environment. Safety is generally enhanced by increasing the rate of airflow to the point where the maximum airflow limitation is reached. It is usual to select fume hoods and to design the air-conditioning system to maintain the face velocity appropriate for the maximum hazards anticipated with the particular hood. Table 1 represents our general recommendations; but modifications in some situations may be warranted.

TABLE 1
Recommended Face Velocities

Degree of Hazard	Minimum Measured Velocity at Any Point Across Hood Face
Low toxicity levels	50 fpm
Average toxicity levels in research involving a wide range of materials	75 fpm
Low-level radioactive tracer materials with nominal toxicity hazards	100 fpm
Significant chemical toxicity levels and moderately radioactive materials	150 fpm
Higher levels of toxicity and highly radioactive materials	Consider the use of glove boxes and total enclosures if velocities in excess of 150 fpm are required

SELECTION OF FUME HOODS

Degree of Hazard. The degree of hazard of the experiments to be conducted within a fume hood has a great influence over the type that should be selected. It is important to establish the maximum degree of hazard anticipated before the choice of a hood is made. Conversely, it is important to know the limitations of each hood so that inconvenience or even tragedy, is not caused through improper matching of experimental work with hood capabilities.

Size of Experiment. For reasons of safety and economy it is desirable that hoods be as small as possible and exhaust the least possible amount of air from the laboratory. However, a hood must be sufficiently tall, wide and deep to house the particular type of experiments that will be undertaken. Experimental apparatuses vary greatly in size; therefore, fume hoods have been designed over a wide range of sizes and shapes. They may be as large as small rooms that are walked into, or they may be small, portable enclosures which are easily carried and placed in different positions on laboratory benches.

A common fault in the selection of fume hoods for science buildings is the tendency to select hoods of uniform size, usually a bench-type, as part of a conception of a modular laboratory arrangement. The program requirements for a science building should give consideration to the potential variation in size of experiments to be conducted so that an appropriate number of various size hoods, with a reasonable distribution within the building, can be obtained.

Fume Hood Construction Materials. A great many materials have been used for fume hood construction. Most of them have proven to be satisfactory when used correctly and properly selected with regard to the requirements of the experiments. It makes good sense to use the least expensive material that will do the job. Unfortunately, however, materials which are most versatile tend to be the most expensive. Table 2 relates fume hood materials with versatility for experimental work and economics.

TABLE 2
Hood Construction Materials
(Listed in decreasing order of cost)

Material	Limitations
a) Hood structure	
Chemical grade soapstone	Most versatile
Stainless steel	May be attacked by some chemicals. Care should be used in selection
Monel metal	May be attacked by some chemicals. Care should be used in selection
Synthetic or cementitious "stones"	Absorb water, tend to stain, may be attacked by some chemicals
Carbonized birch	Recommended only for light service
Aluminum	Recommended only for light service, readily attacked by alkaline materials
Reinforced plastics	Recommended only for light service. Resins vary in resistance to chemical attack and fire resistance. Care should be used in selection
Varnished wood	Limited to the lightest service where no possibility of fire exists and no use will be made of solvents and steam
b) Glazing materials	
Laminated glass	Most versatile
Tempered glass	Not recommended where experiments may produce rapid thermal changes or explosion hazards exist. Although the glass shatters into fragments which are not sharp, failure results in loss of protection
Wire glass	Wires restrict vision
Plain glass	Not recommended
c) Coatings	
Epoxy	Too new for adequate experience but appears promising
Strippable paints	Not resistant to solvents and many chemicals. Use should be avoided except for special radioactive applications and when related to a decontamination program

DESIGN FACTORS

1) The depth of a hood is the most important dimension with respect to satisfactory operation. In general, the deeper the hood the more satisfactory it will be in providing uniform suction across the open face. The depth is also of great importance with respect to the possible size of apparatus and experimental setups that can be contained.

2) Generally, the lower the height of a fume hood (and the clear opening), the more satisfactory will be its airflow characteristics. A very tall hood with the exhaust duct connection near the top will present the greatest risk of escape for fumes because of the difficulty of securing uniform airflow at the base.

3) The design of the jamb is of utmost importance in preventing turbulence at the sides of the hood, which may result in fumes being swept out into the laboratory. In general, the jamb design should permit the smoothest possible airflow pattern.

4) The design of the sill should also provide for a smooth airflow to minimize turbulence. Sill designs which incorporate slots permitting air to enter and sweep across the working surface, irrespective of how close the operator may be standing, are valuable in insuring a safe hood. It is highly desirable that the sill be designed, by means of a slope or curvature near the front edge, to make it impossible for experimental equipment to be placed within 6 to 10 inches from the edge. Such design auto-

matically prevents fume-generating experiments from being positioned close to the front edge of the hood.

5) It is recommended that the sash tracks of a fume hood be installed some distance behind the front edge of the jamb and sill. This automatically insures that the experimental apparatus will be set back to this extent in the hood. In general, the further back the fume-producing apparatus is located in a hood, the greater the safety in the conduct of the experiments.

6) Uniformity of airflow across the face of the hood is of utmost importance. Averages can be deceptive, and a hood with an appropriate, average face velocity may actually provide below-minimum velocity at some points and above-maximum velocity at others. Such a hood can be unsafe. Each of the design factors influences uniformity of airflow across the face. Most important are the proportions of the hood—height, width, depth—and the relationship of the size and position of the exhaust-duct connection with the baffles. Unfortunately, no simple rule of thumb can be provided for guidance; the location of exhaust air ducts, the number of such ducts per hood, plus the type and design of baffles are of equal importance. For simple hoods with only a single exhaust air outlet near the top and with the usual type of slotted panel baffles, it is said that uniformity of airflow across the face will be increased as the hood depth increases, and will decrease with increasing height and width.

7) The function of baffles in a fume hood is to distribute the suction of the exhaust duct in such a way that uniform airflow through the face of the hood will result. The design and position of baffles and their openings are critical to satisfactory performance. Opinions on proper design of baffles vary widely among experts on the subject. At least two baffles, one at the top and one at the back of the enclosure, should be provided; they should be separated by air slots. Dividing the back baffle to form a center slot will improve velocity distribution at the hood face.

8) Many special design conditions occur with fume hoods and their associated components. These special situations should be explored when the program for a science building is being analyzed. Examples of special factors are: when radioactive materials are to be handled in a hood, the construction of the base cabinets and floor must be taken into consideration and the need for shielding blocks which may have a combined weight of 2000 pounds or more; when perchloric acid is to be used, the hood should be provided with washdown facilities and must be constructed so that its interior components and concealed air passages can be cleaned without undue jarring to avoid an explosion.

RELATION OF FUME HOODS TO AIR-CONDITIONING SYSTEMS

The advent of air-conditioning for laboratory buildings has greatly intensified the economic problems in the selection and utilization of fume hoods. The large volumes of expensive cooled air exhausted by fume hoods add substantially to the initial and operating costs of air-conditioning plants. Some mechanical engineers estimate that the initial extra cost of an air-conditioning plant is approximately equal to the installed cost of the fume hoods. In a science building with many fume hoods, the exhaust through this safety device can account for the greatest single cooling load requirement. (Of course, heated air is also lost through fume hoods during the winter, but the cost of heating is generally not as great as the cost of cooling and therefore is of less concern.) Many ideas, both simple and elaborate, have been explored to reduce the volume of conditioned air lost through fume hoods, thereby reducing the initial and operating costs of the air-conditioning system. Unfortunately, a number of these schemes have lost sight of the basic function of the fume hood—providing safety—and have tended to compromise the protection or comfort of the operator in the attempt to reduce air-conditioning costs.

The second important relationship of fume hoods to air-conditioning systems is the problem of maintaining satisfactory balance. In a building where an extensive number of fume hoods are being employed, the simplest approach to this has been to ignore the problem of balance and simply supply additional air throughout the system to make up for the losses through the hoods, on the assumption that about half the hoods may be operating at one time. The effectiveness of such a system seems to fluctuate depending on what actually occurs in use. Other approaches have been taken to control fume hoods and return air registers in a system to provide a constant volume of exhausted air, or to use constant-volume fume hoods as the sole exhaust outlet.

With respect to the air-conditioning system, fume hoods may be divided into three groups:

a) The standard hood is one in which the volume and velocity of air varies as the sash is raised or lowered, since no means is provided to compensate for the variable area of face opening. This type of hood causes the greatest difficulty with balance in an air-conditioning system. Laboratories containing such hoods must be supplemented with additional exhaust air openings to insure adequate laboratory ventilation.

b) The constant-volume hood incorporates an internal bypass feature permitting the same volume of air to be exhausted into the hood regardless of the position of the sash. Such hoods permit balancing of the air-conditioning supply and exhaust. Constant-volume hoods may not be manually controlled but operate continuously while they serve as the air exhaust outlet for the laboratory. It is often incorrectly assumed that this type of hood, because of its greater cost and more elaborate appearance, is safer than a standard hood. The special function of the constant-volume hood is related to the balance of the air-conditioning system rather than to safe operation and does not provide greater safety than can be achieved with a properly designed system using standard hoods.

c) The auxiliary air-supply hood attempts to reduce air-conditioning requirements by providing a separate supply of air that has not been cooled and dehumidified in the summer or fully heated in the winter. The supply of air for such a hood may be drawn from outdoors or from the service chases within the building, which are, in turn, supplied by air from attic or mechanical equipment rooms. Such hoods can substantially reduce the air-conditioning equipment capacity required to make up losses through fume hoods; operating costs can likewise be reduced. However, there are a number of disadvantages to the use of such hoods. One type of auxiliary air-supply hoods discharge untreated air just in front of the face of the hood, usually at the head, a scientist working at the hood must work in unconditioned air. The disadvantages are obvious, and the annoyance of scientists has been evidenced by their very human attempts to invent means of foiling the intended mode of operation. One such effort consists of securing cardboard over the outlets with adhesive tape, thus closing or reducing the auxiliary supply. Attempts to rectify this problem by partially cooling or heating the air supply, depending upon the season, substantially reduce any economic advantage of this type of hood. Another type of hood introduces the auxiliary air within the hood enclosure and is inherently unsafe because the face velocity is reduced below the rate necessary to capture fumes. This type of hood also poses several operational problems that can lead to significant hazards.

Another very important problem with auxiliary air-supply hoods is that the balance between the temperature of the auxiliary air and the air in the hood is critical. Unless balanced just right, much of the auxiliary air will not enter the hood but will enter the air-conditioned space of the laboratory, sweeping with it some of the contaminated air from the hood. Several manufacturers, universities, and public agencies are now attempting to improve upon the design of auxiliary air-supply hoods. For the present, however, it is our opinion that such hoods are usually an unwise selection.

Air supply outlets and returns in laboratories which contain fume hoods should be so located, in relation to the position of the hoods, that they do not cause strong drafts in the vicinity of the hood. If the fume hood is operating with a face velocity as low as 50 fpm, a relatively small draft of air can act to overcome and reverse the desired airflow into the hood and cause a hazardous condition.

CONTROLS

Piped services with outlets inside a fume hood should be controlled by handles in readily accessible locations outside the hood enclosure. If washdown facilities are provided for hoods to be used with perchloric acid, the control valve handle should also be located outside the hood enclosure.

Switches, rheostats and other control devices for electrical apparatuses and convenience outlets located within hoods should be located on the outside of the enclosure. The design of such controls should be approved for use in explosive environments.

Lighting controls, as with other electrical switches, should be located outside the hood enclosure and be of explosion-proof design.

When individual fan control is desired, the control device should be located outside the hood enclosure. Where several hoods are included in a single laboratory space, it is recommended that all hoods be controlled through a single switch, thus insuring that they will all operate simultaneously. It is undesirable to have some hoods operating while others are idle in a single laboratory space, as the idle hoods can serve as sources of make-up air for the hoods which are operating. When this occurs, the make-up air entering the laboratory through the idle hood may pick up sufficient contaminated material from the hood exhaust duct, the hood itself and any experimental apparatus within the hood to cause a hazardous condition in the laboratory.

Occasionally special controls are required for the adjustment of an experimental setup within the hood enclosure. It is desirable that the controls for such installation be located outside the hood in such a way that the sash may be completely lowered. Slots or other means should be provided so that the controls can be conveniently brought out of the enclosure. Should the fume hood be of the type with a sill incorporating slots for airflow, the slots may serve this purpose.

ADJUSTMENT FEATURES FOR AIRFLOW

A number of air-volume controls have been used with fume hoods. Among the more commonly encountered types are dampers in the exhaust duct and multispeed fan controls. We do not recommend the use of dampers as they require extensive maintenance and reduce efficiency of the exhaust system. Multispeed fan controls provide the fume hood operators with a degree of individual control; however, they may cause difficulty with the balance of the airconditioning system by frequent fluctuation of the supply air requirements. The recommended means of controlling air volume is to design the exhaust system carefully with respect to its airflow characteristics and provide the possibility of volume adjustment at the fan in such a way that adjustments can only be made by the operating personnel of the building's mechanical system.

The principal means of controlling the pattern of air distribution within a hood is through adjustable baffles. Such baffles are located between working areas of the hood and the point of connection with the exhaust duct. The baffles must be able to transform the suction of the duct into a uniform flow of air at the fume hood face. Baffles control air distribution by their position within the hood and by the size and position of slots in the baffles; usually the slots are adjustable. Occasionally the position of the baffle is also adjustable. The need for control through adjustments of the baffles increases with increasing height and width of hoods. Very large hoods require very sophisticated baffling systems to insure satisfactory airflow characteristics. The adjustment of the baffles is of extreme importance regardless of the characteristic of the baffle design. Therefore, a critical part of every fume hood installation should be careful adjustment of baffles and subsequent testing.

LOCATION OF THE FUME HOOD IN THE LABORATORY

Air Velocity Outside Fume Hood. The rate of airflow required to satisfy minimum face velocity requirements is quite small. Therefore, air movement outside the hood is of great importance in insuring safe operation. As already discussed, the location of room air outlets and returns may cause drafts sufficient to counteract and reverse the flow of air into a hood. Opening and closing of doors into a laboratory space will move a considerable volume of air and does have a marked influence on airflow patterns and pressure surges within a laboratory. This results in major air movements which can temporarily alter fume hood airflow characteristics. The effect of door openings is so great that considerable caution should be exercised in locating fume hoods in small laboratories where the relative volume of air movement generated by door action is substantial in relation to the total volume. In all laboratories it is desirable to locate fume hoods as far away as possible from door openings.

Windows which may be opened for ventilation can present even more serious interference with fume hood operation than doors. When fume hoods are located in buildings that are not airconditioned, or which require open-window ventilation during the spring and fall, hoods should not be located close to windows which may be open. However, it is preferable that hoods be located only in spaces provided with supply air through a mechanical ventilation system which can control the volume and location of incoming air.

Pedestrian traffic within a laboratory can also interfere with the operation of fume hoods. This can be readily recognized by recalling that a walking speed of one mile per hour is equal to 88 fpm, or 33 fpm greater than the minimum recommended face velocity for fume hoods. A person walking at 2 mph moves at a speed of 176 fpm, which is 26 fpm more than the maximum recommended face velocity for fume hoods. These are very moderate walking speeds; thus it should be assumed that any walking speed will probably exceed the face velocity, and persons walking by fume hoods will tend to produce some flow of contaminated air out of the hood. It is therefore undesirable to locate fume hoods along principal traffic lanes.

Relation to Work Areas. Fume hoods should be located conveniently in relation to benches and apparatuses that may be used by scientists in connection with the same experimental program. It is desirable that fume hoods be integrated with other laboratory furniture in such a way as to provide adequate bench space adjacent.

Proximity to Service Shafts. There are economic advantages in locating fume hoods close to service shafts which will contain the exhaust ducts and piped service lines. Such economic considerations have often been carried to the point where fume hoods have been located in undesirable positions in laboratories with respect to safety. It should be remembered that the function of the hood is to provide a safe working environment, and small savings in horizontal ducts and pipe runs are not worthwhile if the fume hoods cannot serve their intended function. When it becomes necessary to choose between safety and proximity to service shafts, the choice should always be for the location that will provide for proper function of the hood.

TESTING AND ADJUSTMENT

No standard testing procedure has yet been developed for the evaluation of fume hood performance. However, a number of procedures are being used which involve titanium tetrachloride smoke, smoke bombs, hot-wire anemometers and release of odoriferous materials (e.g. ammonia and mercaptans) within hoods. Testing services are available from independent consultants (general industrial hygienists), mechanical engineers and manufacturers' representatives.

At present there is an important need for the establishment of a standardized testing procedure for fume hoods and for fume exhaust system evaluation. Even though we are not satisfied with existing testing procedures, the necessity of adjusting hoods after they are installed and testing them prior to acceptance (as well as periodically during the life of the equipment) cannot be omitted. A satisfactory specification for a laboratory building should incorporate requirements for testing hoods with respect to airflow characteristics and face velocity. Hoods which do not provide satisfactory test results should not be accepted.

FUME HOOD EXHAUST SYSTEMS

Duct System

Ideally, every fume hood should be served by an independent duct. Such an arrangement insures maximum safety and flexibility. Economics, however, favor some degree of combination of ducts. Separate ducts should always be used with hoods for handling of radioactive materials, perchloric acid, strong oxidizing agents, or highly reactive chemicals of any sort. Aside from these cautions it is always permissible to combine ducts from several fume hoods in the same laboratory space, especially teaching laboratories where the work being done in the several hoods is under the control and supervision of an instructor. Hoods in several different laboratory rooms should never have their ducts combined, since it is not possible to predict the simultaneous use of hoods with materials that may be reactive when combined in the air stream. The combination of several hoods into a single duct also greatly complicates servicing problems, as any maintenance or repairs required for the duct or exhaust fan will shut down hood operation in all of the laboratories served by the combined duct.

Fume hood ducts differ from other air-handling ducts in that the materials that pass through them are often highly corrosive and very toxic. Consideration should be given to the fact that such ducts will have to be serviced or replaced during the life of the average laboratory building. Safety to personnel making repairs or replacement of ducts should not be overlooked.

Many satisfactory materials are available for fume hood ducts (see Table 3). Unfortunately, as in the case of fume hood construction materials, they vary in their

TABLE 3
Duct Construction Materials
(Listed in order of decreasing cost)

Material	Limitations of Use
Glazed ceramic pipe	Rarely used today because of installation problems
Epoxy coated stainless steel	Extensive experience not yet available but appears promising as most versatile material
Stainless steel	May be attacked by some chemicals. Care should be used in selection
Monel metal	May be attacked by some chemicals. Care should be used in selection
Synthetic or cementitious "stones"	Absorb moisture, may be attacked by some chemicals
Reinforced plastics	Various resins being used have different chemical and fire resistances. Care should be used in selection
Asphalt-asbestos coated steel	Limited solvent resistance. Care should be used in selection
Aluminum	Limited resistance to many chemicals. Care should be used in selection
Galvanized steel	Limited resistance to corrosion by wide variety of materials used in research
Black steel	Useful only with dry and uncorrosive dusts

cost and versatility of use. Expensive duct materials, such as stainless steel, are not completely versatile and are subject to attack by some chemicals. Therefore, considerable care must be exercised in evaluating the type of materials to be used in laboratories, the selection of duct materials and the features provided in the design of the building for service and replacement of ducts.

High-velocity air movement in the ducts is desirable to insure that dust and aerosol-size materials are not deposited in the joints, cracks or corners in the duct system. A minimum suggested design velocity is 2000 fpm. Higher conveying velocities are desirable. A minimum of turns, bends and other obstructions to airflow are desirable. Where perchloric acid is to be used, duct configuration should permit thorough washdown of duct surfaces.

Exhaust Fans and Outlets

Location of the Fan. Early in the history of the use of fume hoods, it was common to install exhaust fans directly above the hood. This has been found to be a very unsafe practice because it creates a high-pressure condition in the exhaust ducts and any leakage at joints or through pinholes caused by corrosion may result in distribution of contaminated air and toxic materials into the building. Unfortunately, some hoods are still being installed with fans located above the hood within the occupied space of the laboratory. This unsafe practice should be eliminated entirely, and we hope that building codes will eventually be revised to incorporate this requirement.

Locating the fan of a fume hood exhaust system in an attic or mechanical equipment room is less than wholly satisfactory, although a great improvement over a location directly at the hood. When the fan is located within an attic or a mechanical equipment room, there is a possibility of leakage into the building before the duct penetrates to the exterior where the fumes can be safely discharged. Attics and mechanical equipment rooms containing fume hood ducts in which the pressure is higher than in the surrounding space should be mechanically ventilated to the outdoors. Joints in ducts containing fumes under pressures should be sealed with compounds especially formulated for the purpose.

The preferred location for fans is outside the building, usually on the roof, and as close as possible to the terminal. Such a location insures that the ducts within the building operate at lower pressure than exists within the surrounding spaces in the building and that any leakage that does occur will be into the duct.

Location of the Discharge Terminal. When fume hoods are installed in existing buildings that have not been provided with adequate service shafts, the discharge will sometimes be made at the side of the building. Usually the duct will be carried through a panel substituted for a pane of glass in a window. This practice is unsafe and should be discontinued. The possibility of re-entrance of fumes through opened windows of the same or adjacent buildings is very great. Also, discharge at this position may result in noxious fumes collecting in the vicinity of the building rather than being swept rapidly away when the discharge coincides with being on the leeward side of the building.

Fume hood ducts are occasionally discharged into stacks which carry fumes to a point high above the building for discharge into the air. There are a number of architectural design problems associated with this type of discharge; however, the use of tall stacks may help solve the problem of safe disposal of especially toxic matter.

Occasionally fume hood exhaust ducts discharge their contents into areawells below grade. This may occur as a simple way of exhausting a fume hood located in a basement or subbasement space. This practice is not recommended, as toxic materials may accumulate in the areawells where they cannot be swept away by air movement. Fumes discharged in this way may also pass through on-grade areas where building personnel must walk and would be subjected to hazards. Occasionally rooftop wells are created as a result of screening, skylights or other architectural features on roofs. Discharge outlets of fume hood exhaust systems located within such depressed or screened areas are unsatisfactory, as this kind of arrangement tends to prevent the fumes from being swept away from the building.

The preferred location for fume hood exhaust duct discharge terminals is above the roof of a building. Ideally, the point of discharge should be above the transition zone between air moving freely past the building and the turbulent air restrained or trapped on the roof or lee side of the building.

Horizontal fan discharge outlets, fixed cap outlets, mushroom cap outlets and rotating cap outlets tend to prevent discharged noxious materials from being projected upward into the air stream which will move them away from the building. The preferred type of discharge terminal projects the fume hood exhaust air in a vertical direction at the highest possible velocity so that it can be captured by the free air stream above the turbulent zone influenced by the shape of the building. The only positive way of accomplishing this is to carry the discharge terminal to a sufficient height so that it is above the boundary between air flowing past the building rather than captured on the roof or in the leeward wake.

The function of the discharge terminal of a fume hood duct system is to project fumes away from the building in such a way that air intakes will not be contaminated and persons in the vicinity of the building or working on the roof will not be subjected to the hazard of breathing the discharged fumes. A common observation is that concern about rain entering the discharge end of the duct has led to a design decision negating this fundamental consideration. Discharge outlets of exhaust fans have been aimed downward to spread fumes along the surface of the roof or they may discharge horizontally which is nearly as bad. The fans may be positioned to discharge vertically but the opening of the duct terminal is covered by some type of weather cap, which reduces velocity and changes the direction of discharge so that the fumes are not projected away from the building. Such concern over rain penetration is needless as very simple means of protecting the fan can be found that do not compromise the effectiveness of the system. To begin with, it should be remembered that an appropriate terminal velocity of at least 2,000–3,000 fpm (609.6–914.4 m/min) is sufficient in itself to prevent rain penetration of the stack. The column of air leaving the terminal simply brushes the rain aside. If the fan is not operated continuously, there is the possibility of some rain penetration but this can easily be handled by a small drain hole at the bottom of the fan housing, or the use of one of a variety of details that have the effect of creating a drip within the duct to divert water and discharge it before entering the fan housing.

When radioactive materials are used, filters may be required to prevent discharge of these materials into the air. Scrubbers, burners and other types of air cleaners may also be used to treat fume hood discharges and reduce the potential hazard from toxic, biological and radioactive wastes. Filters and scrubbers can also partially reduce the need for concern over location of discharge terminals with respect to air intakes, experimental apparatus located on the roof and to personnel who may work there.

HAZARDS ASSOCIATED WITH FUME HOOD DISCHARGES

The problem of designing a satisfactory fume hood is not concluded with the hood, duct, fan and discharge terminal. Consideration must also be given to what happens when the fume hood exhaust leaves the system and enters the open air. As suggested in the previous section of this chapter there is considerable danger that the fume hood exhaust may circulate back into the building of its origin or into adjacent buildings. Special care should be taken to protect air intakes against contamination, and model tests in wind tunnels are often desirable for the study of complex situations. Corrosive fumes released a short distance above a laboratory roof can cause deterioration of scientific apparatus and rooftop mechanical equipment such as fans, and cooling towers. There may be considerable potential hazard to personnel, both scientific and building maintenance, who may have occasion to work on the roof of the building.

One of the most popular misconceptions is that an air intake at ground level will be adequately protected by a separation of several stories between it and fume hood discharge terminals on the roof. This conception is contrary to our understanding of airflow behavior around buildings and is not supported by observations of the performance of existing science buildings. One example is a university biochemistry research laboratory that is five stories high. The air intakes are located at ground level and fume hood outlets and an incinerator outlet are located on the rooftop. This building is a long slab with its major axis oriented in the northeast-southwest direction. The air intake is located near the center of the southeast elevation which turns out to be the prevailing leeward zone. The experience supports theoretical considerations completely as strong solvent and chemical odors are distributed throughout the building by the ventilating system with daily regularity. The five story separation here has not provided protection.

Studies of airflow around buildings both in the field and in wind tunnels show that a building forms an obstruction to airflow resulting in displacement of air. A cavity is formed on the leeward side of the obstacle in which relatively limited air movement takes place between the cavity and the surrounding regions. The shape of the cavity is influenced by the shape of the building and other nearby obstructions to airflow; the velocity of airflow and other meteorological conditions. Air intakes should not be located in positions that are likely to fall within the prevailing leeward side of a science building. However, this advice is really dependent upon the point at which the fumes are discharged from exhaust stacks. If the fumes are discharged at a height above the boundary of the cavity zone, then they will be carried away from the building and not contained within the cavity, however, if the height is not sufficient for the fumes to be discharged above the boundary they may be contained and held within the cavity. If the air intakes are also within the cavity region, they will draw in contaminated air.

There is no simple way to tell how high stacks should be to penetrate the cavity boundary. Photographs made of smoke moving past actual buildings, and simulation studies in wind tunnels show that the separation of the cavity from the air stream moving past may be sharply defined. However, the shape of the cavity and the height of the boundary for a given building shape will vary with wind speed and be influenced by such meteorological conditions as wind gust factors. There are a number of papers in the literature describing studies in which wind tunnel tests have been used for making a good approximation of the optimum height to insure dispersing fumes away from the vicinity of the point of discharge. Some authorities have formulated a rule of thumb which says that the height of the discharge point should be half again the height of the building. (By building height they are referring to the elevation of the leading edge or separation point at which the cavity begins to form.)

We are reluctant to support this rule of thumb because it is too conservative for many situations. It is increasingly conservative as buildings become taller and is also substantially influenced by the aerodynamics of the building shape and the relationship of the shape to the direction of the prevailing wind. Some smoke flow studies of low buildings, however, make the rule of thumb appear reasonably valid. It is interesting to think about this because one of the commonly made mistakes in the design of science buildings is the attempt to hide fans, stacks and other equipment on roofs of science buildings by means of parapets, wells, and other types of rooftop construction in the hope of giving the building a neater, more orderly appearance. Such obstructions to airflow simply aggravate the situation by making it necessary to raise the height of the stacks still further. If this is not done, fume dispersal from the rooftop area will be seriously compromised. It can lead to potentially hazardous conditions to all persons who must work on the roof while fume hoods are in operation since the parapets and wells tend to retain fumes to even a greater extent than if they had not been constructed. Solutions to this problem can be found readily once it is recognized that stacks are a necessary part of a science building ventilation system and the aesthetic design must incorporate some provision for accommodating them. A number of buildings have already been designed in which a series of stacks are visible, undisguised, but so treated and organized that their appearance is entirely acceptable as a component of the form. This approach makes much more sense than trying to cover them up with false roofs or parapets which defeat their own purpose by making it necessary to raise the stacks still higher.

One of the most important kinds of information when planning a science building with fume hoods is the pattern of wind direction distribution at the site. Most people have general notions of the prevailing wind direction, however, such general notions, usually expressed in such terms as —"Our prevailing winds are from the west, except in the winter when we have strong winds from the southeast."—are generally useless. What is needed is an indication of the prevailing percentage distribution of occurrences of wind from the various points of the compass. Even more important than knowing the direction the wind is coming from most often, is knowledge of the direction the wind comes from least often. It is the prevailing leeward zone of a science building that is the critical area with respect to the location of air intakes. By examination of a number of wind rose patterns for different sites, it can be seen that the prevailing leeward direction is rarely 180° opposed to the prevailing windward direction, which is the popular conception.

The quality of wind direction distribution information available at the present time is a great weakness in rational design of fume dispersal systems and location of building air intakes. Unless a proposed new science building is part of a college or university that is fortunate in having a Meteorology Department or some other academic unit or research group collecting wind distribution data for a period of years, it is necessary to fall back on the data available from the nearest Weather Bureau Station. This is far better than no information, but cannot be responsive to the variations introduced by local geographic circumstances. An alert university, industry or other user of fume hood systems, requiring construction and renovation of a substantial amount of facility space over the years, should make an effort to collect wind distribution data using recording equipment located in the areas where new construction is anticipated. Such information could become very valuable base data in science facility planning.

The problems associated with fume hood discharge, and airflow and gas diffusion around buildings require extensive research. However, considerable information has already been accumulated on these subjects and is available in the literature.

ADDITIONAL INFORMATION

This chapter has attempted to briefly outline the principles for satisfactory use of fume hoods for science laboratories. We have attempted to describe all of the elements of the system without becoming involved with details. Therefore, the information in this chapter should not be considered to be sufficient for design criteria or the preparation of specifications. A collection of literature on fume hoods and related subjects is available for reference in the offices of the Architectural Services Staff of the National Science Foundation in Washington. Architects who are planning science buildings are invited to visit and study this material. An extensive bibliography is available upon request.