Aerosols are among the most important potential cause of infections in laboratories. Many routine processes and laboratory procedures are capable of producing aerosols that may cause infections if inhaled. Small aqueous droplets evaporate quickly and the remaining solids, including the infectious agents, may remain airborne for long periods and be carried by ventilation systems in buildings.

Control of Biological Hazards[2]

The best approach to controlling biological hazards is to contain them at their source. To reduce infection, measures are directed at any of the links in the chain of the infectious process, for example: containment, isolation, and disinfection (directed at the causative agent); personal protection (aimed at the mode of entry); and vaccination (directed at the host). There are specific and general precautions that are to be implemented to reduce the risk of transmission.

PRECAUTIONS

The most important guidelines for biological safety in laboratories revolve around good laboratory practice, laboratory design, and equipment. Recommended biosafety equipment includes: pipetting aids, centrifuges, autoclaves, incinerators and biological safety cabinets. Biological safety cabinets should be used for all laboratory procedures with a high potential for creating hazardous aerosols and whenever high concentrations or large volumes of infectious agents are handled. Specific precautions relate to the biological agents being handled. Agents are classified according to risk, taking into account the method of transmission, the infectious dose, and the implications of the disease to the human host.

Biological Safety Cabinets

At the present time there are three major classes of biological safety cabinet. Class I cabinets are the simplest and provide an inward flow of air away from the operator (Figure 8-15). Class II cabinets have an air barrier to protect the operator and a laminar flow of filtered air over the work area in order to protect the working material (Figures 8-16 and 8-17). Class III cabinets are totally enclosed units incorporating built-in gloves and a special means of entry and exit for work materials (Figure 8-18). Exhaust air must pass through high efficiency particulate air (HEPA) filters on the Class I and II cabinets while both intake and exhaust air is filtered on Class III cabinets. Laminar flow clean benches are also used in microbiological laboratories (Figure 8-19). These are not to be used when handling infectious material as they provide product protection only (ACGIH®, 2007).

[2] This topic is covered in detail in Volume 2, Chapter 7.

The classes and features of various types of biological safety cabinet are similar in most western countries. Table 8-2 lists the features of biological safety cabinets according to the Centers for Disease Control and Prevention and National Institutes of Health in the U.S. (CDC/NIH, 1995). These are similar in important respects to those in Australia and elsewhere (Standards Australia, 1991). Most biological safety cabinets should not be used as chemical hoods. They are only fitted with particulate filters and recirculate a portion of the exhaust air back into the cabinet and the remainder back into the room (unless they are connected by duct-

Table 8-2
Features of biological safety cabinets (adapted from CDC/NIH, 1995)

Type	Face *v* f/min (m/s)	Airflow Pattern	Radionuclides/ Chemicals	BSL	Product Protection
Class I*	open front 75 (0.375)	In at front; rear and top through HEPA filter	No	2, 3	No
Class II Type A	75 (0.375)	70% recirculated through HEPA; exhaust through HEPA	No	2, 3	Yes
Class II Type B1	100 (0.5)	30% recirculated through HEPA; exhaust via HEPA and hard ducted	Yes (Low levels and volatility)	2, 3	Yes
Class II Type B2	100 (0.5)	No recirculation; total exhaust via HEPA and hard ducted	Yes	2, 3	Yes
Class II Type B3	100 (0.5)	Same as IIA, but plena under negative pressure to room and exhaust air is ducted	Yes	2, 3	Yes
Class III	NA	Supply air inlets and exhaust through two HEPA filters	Yes	3, 4	Yes

* Glove panels may be added and will increase face velocity to 150 f/min (~ 0.75 m/s); gloves may be added with an inlet air pressure release that will allow work with chemicals/radionuclides.

ing to the outside of the building).

The ventilation requirements corresponding to various safety levels are summarized below. The design of BSL-3 and particularly BSL-4 laboratories is a serious matter and full reference should be made to the appropriate regulations and standards and the local authority when any work or alterations to such laboratories is contemplated.

BIOSAFETY LEVEL 1 (BSL-1)

Special ventilation or containment devices or equipment such as a biological safety cabinet are generally not required for manipulations of agents assigned to Biosafety Level 1. The laboratory may have opening windows provided that they are fitted with fly screens.

BIOSAFETY LEVEL 2 (BSL-2)

There are no specific ventilation requirements for BSL-2 laboratories. However, when new BSL-2 facilities are being planned consideration should be given to installing mechanical, negative pressure ventilation systems. Biosafety Level 2 is similar to Biosafety Level 1 but differs in several respects including the requirement that certain procedures in which infectious aerosols or splashes may be created are conducted in biological safety cabinets or other physical containment equipment. Biological safety cabinets should be installed so that fluctuations in the supply and exhaust air do not adversely influence the containment. They should be located away from doors, from windows that can be opened (fitted with fly screens), from heavily trafficked laboratory areas, and from other disturbances.

BIOSAFETY LEVEL 3 (BSL-3)

BSL-3 laboratories should be provided with a ducted exhaust air ventilation system designed to draw air into the laboratory from clean areas and toward contaminated areas. No exhaust recirculation should take place from the contaminated areas. The exhaust air may need to be HEPA-filtered (not always necessary for BSL-3 laboratories) and should be discharged safely away from air inlets and occupied or public outdoor spaces. Flow indicators and alarms are recommended but are not compulsory. All windows are to be closed and sealed.

The exhaust from biological safety cabinets, passed through HEPA filters can be recirculated into the laboratory (the cabinet must be tested and certified at least annually). Centrifuges and other equipment that may produce aerosols should be contained in enclosures and the exhaust air passed through HEPA filters before discharge into the laboratory, or vented externally. Other air handling equipment such as vacuum lines should be protected with liquid disinfectant traps and HEPA filters.

BIOSAFETY LEVEL 4 (BSL-4)

Biosafety Level 4 is only for work involving highly pathogenic and infectious agents representing a high risk of life-threatening infections, e.g., Lassa virus. There are two types of BSL-4 laboratories: One type relies on the use of Class III Biological Safety cabinets (sometimes called a cabinet laboratory). Another approach is to place all the laboratory staff in one-piece positive pressure protective suits and to use Class II biological safety cabinets (Suit Laboratories).

BSL-4 "Cabinet" Laboratory Facilities

The laboratory must be either a separate building or an isolated part of a larger building provided with a dedicated non-recirculating negative pressure ventilation system. The airflow is arranged to travel from areas of lower to higher contamination and the flow from each area is monitored continuously with alarms to indicate inadequate flow. The Class III cabinets are connected directly to the exhaust system. Both the supply and exhaust air pass through HEPA filters designed to permit decontamination or sealing prior to removal.

Equipment and materials can enter only via an airlock, autoclave, or fumigation chamber and must be decontaminated before leaving. Staff must enter and leave the laboratory only through a decontaminating shower room with a full change of clothing. Doors must be sealable and drains connected to a liquid waste decontamination system. Sewer vents and other services must be equipped with HEPA filters. Windows should be avoided, but if any are installed they must be breakage-resistant and sealed.

BSL-4 "Suit" Laboratories

BSL-4 suit laboratories are similar to BSL-4 cabinet laboratories in construction. Work is conducted in one-piece positive pressure suits ventilated by *life-support* systems including back-up breathing air compressors, spare air tanks and alarms. Entry is via an airlock and the suit surfaces are decontaminated before leaving the area. Entrances and exits are sealed. All air exhausted from the facility passes through two banks of HEPA filters (tested and certified annually) and is discharged via an elevated stack outside the building. The filter banks are designed for decontamination or sealing prior to replacement. The filtered air from Class II biological safety cabinets is discharged into the laboratory or directly into the exhaust air system.

QUESTIONS

8.1. What is the difference between a laboratory chemical hood and a laboratory fume hood?

8.2. What is the main purpose of a chemical hood?

8.3. What problems can be associated with older style chemical hoods that do not have a bypass or variable fan speed control?

8.4. Can the face velocity of a chemical hood be increased indefinitely in order to improve the level of containment provided by a chemical hood?

8.5. What chemical hood face velocity is recommended by authorities?

8.6. What methods can be used to control the flow rate of a hood as the sash is raised or lowered?

8.7. What is a main drawback of variable air volume chemical hoods?

8.8. How is the face velocity maintained at a constant value in a bypass chemical hood?

8.9. What are the advantages and disadvantages of auxiliary air chemical hoods?

8.10. What special features should a chemical hood have to handle perchloric acid?

8.11. What are the advantages and limitations of most recirculation (ductless) chemical hoods?

8.12. Can chemical hoods be located anywhere in a laboratory?

8.13. What restrictions apply to equipment that can be placed in a chemical hood?

8.14. How can a smoke test be used to help assess the performance of a chemical hood?

8.15. How can the face velocity of a chemical hood be measured?

8.16. How can the containment of a chemical hood be measured directly?

8.17. How should the exhaust from a negative pressure laboratory glove box be treated to prevent contamination of the laboratory?

8.18. What are the general features of a Class I biological safety cabinet?

8.19. What are the general features of a Class II biological safety cabinet?

8.20. What are the general features of a Class III biological safety cabinet?

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9

HEATING, VENTILATING AND AIR CONDITIONING (HVAC)

Ventilation with fresh air is required for every human occupancy. This chapter covers dilution ventilation control of indoor air quality (IAQ) in non-industrial employee occupancies (e.g., offices and commercial buildings) through heating, ventilating and air conditioning (HVAC) systems. Although other control approaches (e.g., local exhaust ventilation) are often used in conjunction with HVAC (e.g., in the control of odors in bathrooms, kitchens, and duplicating rooms), IAQ control in non-industrial occupancies primarily relies on the use of general dilution ventilation. These terms are defined in the next section. See Chapter 8 for more information on dilution ventilation in industrial occupancies. See the end of the chapter for definitions and terms unique to this field and EPA (1991), NADCA (2006), and SMACNA (2002) for more information on this subject.

GENERAL OVERVIEW OF THE IAQ PROBLEM

Background and History

Indoor air complaints began in earnest in the late 1970s because of a number of factors that coincided. These included:

- tighter building construction for energy conservation
- reduced levels of outdoor fresh air provided to building interiors
- new building and construction materials, e.g., insulation foams, glues, fabrics, particle boards, fibrous glass
- larger percentage of time spent indoors, now 90%
- increased public awareness, education, and expectations

- new and proposed legislation, regulations, codes and standards.

Historically, indoor air quality has been related to comfort, temperature, humidity, drafts, stuffiness, and odor control. Generally, comfort is experienced for 80–90% of building occupants when the following conditions are maintained in the occupied space (See ASHRAE Standard 55-1992 for detailed information on indoor air thermal comfort standards):

- Temperature = 68–76°F (20–24.5°C) with less than about 2–3°F variation from place to place or floor to ceiling within an occupied space
- relative humidity (RH) = 40–60%
- There are no odors, drafts, or stagnant areas

Since 1980, attention has increasingly been paid to health problems and complaints resulting from poor indoor air quality. Even low concentrations of indoor contaminants may sometimes result in physical and psychological symptoms and complaints, particularly among hypersensitive persons. The industrial hygienist is often called upon to determine ventilation needs for the maintenance of good air quality in employee occupancies.

Sources and Causes of IAQ Complaints and Symptoms

What are the major sources and/or causes of IAQ complaints and symptoms? At one end of the spectrum is *mass psychogenic disease* caused by the suggestion that people should be feeling sick. At the other end are contagious diseases (colds, flu) that are passed around the plant or office. In either case, time and education often alleviate the problem. Between these two extremes are a number of exposure scenarios related to air contaminants that can genuinely create complaints, symptoms, and illnesses. Exposures to the following may lead to complaints. (Greater detail on these factors is presented in Chapter 5 of Volume 2.)

Volatile organic compounds (VOCs) and reactive organic compounds (ROCs). The presence of reactive organic chemicals (e.g., formaldehyde) may cause complaints and health problems. The source of chemicals can include emissions from building equipment, building materials, furnishings, carpet, and people.

Bioaerosols. The presence of pollen, bacteria, fungi and organic toxins that derive from live microbial organisms in the air may result in hypersensitivity pneumonitis (HP) and other respiratory complaints such as rhinitis and asthma. These often originate in the ventilation system. Such syndromes have taken on names such as *humidifier chills* or *fever*. Now it is known that more significant illnesses (e.g., Legionnaire's disease) are also associated with air handling equipment.

Airborne particles. Aerosols (e.g., tobacco smoke, dusts, mists) may cause similar complaints to those described above.

Confounding factors. Other factors such as temperature, noise, air movement, and indi-

vidual reactions such as those of the immune system can affect the outcomes of exposures to these sources on building occupants. Air contaminants usually originate from within the building, but outdoor sources can also be involved, e.g., motor vehicle exhaust, pollen, re-entrained exhaust air, smoke, wind-blown dust, and so forth.

Typical IAQ Complaints, Symptoms, Illnesses

The National Institute for Occupational Safety and Health (NIOSH, 1987) compiled a list of the frequency of complaints (Table 9-1) in the *problem* buildings it has investigated. Although no definitive answer has emerged, occupant patterns and building features associated with sick building syndrome (SBS) have emerged. These include:

- Not all occupants have complaints.
- Symptoms are often nonspecific or subjective (e.g., fatigue).
- Forced ventilation and/or central air conditioning is common.
- Room humidifiers are sometimes involved.
- The space is often under-ventilated.
- Buildings are *energy efficient*.
- Buildings have carpets.

Table 9-1
Complaints found by NIOSH (1987) in IAQ-problem buildings

Complaint	Percent of buildings where occupants registered complaint
Eye irritation	81
Dry throat	71
Headache	67
Fatigue	53
Sinus congestion	51
Skin irritation	38
Shortness of breath	33
Cough	24
Dizziness	22
Nausea	15

- Air is perceived to be *dry*.
- Complaining people also perceive they have little control over their environment; they feel stressed.
- Building occupant densities are higher.
- Symptoms are more likely in the afternoon than in the morning.
- Females are more likely to experience SBS.
- Atopic (those with allergies) and asthmatics are more likely to experience SBS.
- No single air contaminant (e.g., mold spores, bacteria) or group of contaminants (e.g., TVOCs) have been shown to be the *cause* of SBS; none have been correlated statistically with SBS complaint prevalence.
- Symptoms often disappear after leaving the building.

The HVAC System's Contribution to IAQ Problems and Complaints

NIOSH (1987) has reported that over half of all IAQ problems are related to deficiencies in ventilation and HVAC systems. Such deficiencies include:

- inadequate quantities of outside air provided to the building for dilution of air contaminants
- inadequate distribution of air within the building
- inadequate mixing of air at the occupant space
- uncomfortable temperatures and humidities
- entrainment of outdoor contaminants by the air handling system
- contamination sources in the air handling system itself.

NIOSH (1987), in its studies of numerous IAQ episodes since the 1970s, categorized major sources, causes, or factors as follows (estimates are rounded to nearest 10%). Note that half of the problems were attributed to the HVAC system itself.

- 50% related to deficiencies in the ventilation of the building (e.g., lack of outside air, poor air distribution, uncomfortable temperatures and humidities, and sources of contaminants in the system).
- 30% related to some indoor air contaminant (e.g., formaldehyde, solvent vapors, dusts, microbiological agents).