Laboratory design

9

DUNCAN LISLE-FENWICK

9.1 Introduction

9.1.1 A need for quality control

Safety has escalated to number one on the agenda of pharmaceutical companies worldwide. Quality Control is the mechanism by which safety is achieved and measured and the Quality Control (QC) laboratory provides a crucial and integral role in achieving the safety objective.

There is a wide spectrum of laboratory types, from schools through to genetic research, undertaking tasks which may take only a few minutes or literally years to complete. The focus of this chapter is on QC laboratories and their purpose, operational requirements and design features, many of which are common to other laboratory types. The QC laboratory has an important place in pharmaceutical production. The activities undertaken in the laboratory rarely contribute directly to the pharmaceutical manufacturing process, but the function of the laboratory remains essential to the final product.

9.1.2 Complex issues require clear procedural guidance

Earlier chapters provide a basic understanding of the complexity of pharmaceutical production. To appreciate how important it is to have a structured and quantifiable approach to any production process it is necessary to examine the process beyond chemistry and biotechnology. Dividing the process into functional categories reveals opportunity for failure error in each. In developing an understanding of how, even within the most highly automated facilities, there is infinite scope for something to go wrong, it is clear that due attention should be paid to the preparation and implementation of safe operating procedures. Consider the implications for controlled functionality in each category:

- facility:
  - construction and materials;
  - maintenance and cleaning;

  - age — wear, corrosion, deformity;
  - control and measure — accuracy, calibration;
  - warning systems — detection and alarm.
- operatives:
  - skill level — training, experience;
  - awareness — familiarity, tiredness;
  - attitude — positive, safety conscious, composed.
- environment:
  - temperature, humidity, air flow — direction, velocity;
  - contamination — to the product, to the environment;
  - hazardous — explosive, flammable, toxic.
- raw materials:
  - quality — composition, constitution;
  - storage and transportation — stability, containment, shelf life;
  - dispensing, handling, containment.

Design, construction and operating codes and standards exist to ensure all factors are given due consideration and a consistent approach. The designer, constructor and operator use knowledge and experience in the endeavour to provide a facility which functions safely and correctly time after time.

In pharmaceutical production scientific accuracy is the major factor contributing to repeatability. Accuracy is the degree to which measurement can be recorded. The principle measurements are: weight, volume, velocity, duration (hence flow rate), temperature and pressure. Measurements apply to solid, liquid or gas states or any combination producing slurries, solutions, vapours etc. Precise measurement is essential to avoid potentially catastrophic reactions and of course it is crucial to the effective product formulation. The process itself introduces stringent specifications for equipment and machinery to attain the high tolerances imperative to the uncompromising quality demanded.

9.1.3 What is the purpose of quality control laboratories?

The pharmaceutical process involves design, material selection, product manufacture and finishing. Each process conforms to codes of practice, regulatory standards and statutory legislation in an effort to produce consistent product quality. A clearly defined, structured and regulated process is the quality assurance demanded by the market for any product to succeed. Quality control establishes the measure of confidence that the market has in any product. All products rely upon consumer confidence.

Manufacturers build their reputations on the quality of their products, reputations that are established by years of faultless products. Reliability can only be achieved through strict quality control. Pharmaceutical production demands strict quality control maintained by thorough checking and inspection, constant monitoring and rigorous testing performed scientifically against exacting specification criteria — enter the quality control laboratory.

9.1.4 What purpose do quality control laboratories serve in pharmaceutical production?

To appreciate how important quality control is to pharmaceutical production, the analogy of a familiar, tangible product, similar, albeit simpler, in process to that operated in pharmaceutical manufacture will be used. Consider the humble cornflake, we know exactly what to expect, a consistent product time after time. Quality control procedures guarantee to deliver the same quality product virtually every time. Confidence that quality is maintained, the product is purchased without hesitation or doubt, yet the level of quality control that produces cornflakes to satisfy the publics' discerning palette is not high enough to meet the demands of pharmaceutical production. On the rare occasion that a burnt cornflake is encountered in the breakfast bowl, it is simply removed without thought. Subconsciously, a quality control inspection has been conducted, as happens every day before anything is bought or consumed. This ultimate quality control inspection is an impossible task when applied to a pharmaceutical product. Typically the product is artificially coloured, artificially flavoured and has an artificial aroma. To further confound the senses, the active ingredient is a fractional component of the dosage form. Consequently, human senses and judgment cannot be relied upon to verify the quality of pharmaceuticals. Fortunately, manufacturers can be relied upon to supply the precise dosage of active drug every time.

9.1.5 How does the quality control laboratory benefit pharmaceutical production?

Regulatory compliance is the subject of Chapter 2 and reference should be made to that chapter for a detailed understanding of regulatory aspects. With regard to QC laboratories, regulatory compliance is concerned with the continuance of the product licence. Laboratory samples and test results must be strictly maintained and catalogued for easy access. Product traceability is essential as it is the essence of validation. Should the burnt cornflake scenario ever occur in a pharmaceutical product, the consequences could be fatal and widespread, and it is vital that the root cause is quickly identified and isolated. The priorities for traceability are:

- prevention of further unnecessary victims arising;
- evaluation and quantification of the problem;
- possible development of an antidote;
- identification of other affected products;
- rectification of the root cause.

Validation is an all-encompassing process; it begins at the design stage and continues through into operation. Each step must satisfy regulatory guidelines and be precisely documented. This approach to pharmaceutical production is known as Good Manufacturing Practice (GMP) (see Chapter 3).

Quality control is one thing, but care must be taken not to confuse validation with quality control. Quality control is an integral part of validation. The onerous procedures pursued in securing a validated product must only be applied to the appropriate steps of the process to avoid unnecessary expense administering the procedures and exhausting effort maintaining the high standards that are a prerequisite of the regulatory authorities.

Perhaps surprisingly, regulatory compliance is complementary to commercial viability. Commercial viability of pharmaceutical products relies on consumer confidence in the product. This confidence is based on the manufacturing companies reputation. The company's reputation is built on their ability to demonstrate repeatability and reliability. Independent regulation provides an ideal vehicle for marketing that ability. There are other commercial benefits to GMP. Pharmaceutical manufacture is an expensive business, whether batch or continuous process. Rigorously structured and controlled production improves efficiency, reduces waste and manages plant shutdown. Large pharmaceutical companies lead in the field in development and improvement of production facilities. Whether inadvertently or planned, developments in manufacturing technique and improvements in equipment and control systems have led regulatory authorities to raise the standards of acceptability.

9.2 Planning a laboratory

9.2.1 Design concept

The most important factor in designing a laboratory is safety.

Aspects of safety that should be considered when evaluating laboratory design should fall into two categories:

- physical space;
- air flow control.

Physical space

The definition of physical space is controlled by a number of criteria, often conflicting and always challenging the skill of the designer to harmonize between regulatory compliance, functional requirement and available space.

Function and operation

Establish the activities undertaken in the laboratory. Determine the space requirements for each activity and any special features associated with the function.

- **bench space**: Typically determined by the laboratory equipment size and any peripheral equipment such as PCs and printers. Depth should be considered as well as length;
- **bench height**: 900 mm is standard for activities undertaken from a standing position with normally transient attendance by the operator. Stools are usually provided for occasional use. 750 mm is standard for activities conducted in a seated position, usually where the operation duration is extensive;
- **bench frame construction**: A variety of frame options are available, generally of steel construction. Each provides a combination of features:
  - underbench unit: floor standing or suspended;
  - frame visibility: exposed or concealed;
  - structural support: floor or wall and/or spine;

  Selection of a frame type will depend on a number of criteria:
  - flexibility: ease of repositioning/replacing units;
  - cleaning: access to floor space below and behind unit;
  - integrity: load capacity depends upon combined structural integrity of structural supports, the frame and the under bench units;
  - appearance: exposed frames can dominate the overall appearance; carefully considered, they can add feature interest to the laboratory design. Concealed frames reduce the amount of dirt traps providing a more hygienic aesthetic;
  - cost: flexibility, cleanliness, strength and aesthetics each come with a price tag — specify appropriately to the task duty and responsibly to respect the budget;

  - special: special heavy-duty frames with anti-vibration mounts are available where vibration sensitive equipment is to be used such as finely calibrated balances.
  - storage space: well-planned and ample storage is essential to safe laboratory operation. Every instrument, container, reagent etc. should have a dedicated and purpose designed home to promote efficiency and safety in the laboratory. For this reason, a diverse range of storage unit types are available; from a simple, eye level, glass reagent shelf to special ventilated cabinets in fireproof construction with automatic door closers.

The range of storage unit styles is too extensive to list here. Each manufacturer has a large selection of modular units to complement their laboratory bench systems. A popular solution to storage problems is storage wall systems, integrating a variety of unit types within a modular frame over the entire length and height of a wall. The generic requirements for each type of storage unit are discussed in this chapter.

Typical types of storage to be considered include:

- **under bench**: Cupboard, drawer or combined units. Internally cupboards may be provided with shelves or may house equipment such as vacuum pumps, waste disposal units, etc. Drawers may be supplied with an array of guides specifically designed to hold equipment, glassware, etc. in an efficient, tidy and safe manner;
- **safety cabinet**:
  - personnel emergency safety equipment;
  - breathing apparatus — gas masks etc.;
  - first aid — medical kit and instruction;
  - fire fighting — hand held extinguishers;
  - hazard spillage — absorbent sand.
- **pull-out storage**: Each with entire pull-out units or individual pull-out shelves. Each designed to provide easier access to otherwise deep storage space where there is a risk of upsetting objects stored close to the front. It is particularly useful for glassware and chemical storage;
- **solvent/flammable storage**: Provided with a system of mechanical extract ventilation discharging to atmosphere, designed to prevent the build up of flammable vapours within the cupboard. Enclosed in a fire resistant casing to contain any fire for a specified period. Fitted with an automatic door closer that is activated on detection of fire. This type of cupboard may be fitted with carousel, rotary shelving to reduce the risk of accidental spillage whilst containing any vapours within the cupboard. Shelves are lipped and a

removable collection tray is housed in the bottom of the cupboard to contain any spillage;

- **acid/alkali/chemical storage**: Provided with a system of mechanical extract ventilation discharging to atmosphere, designed to prevent the build up of toxic fumes within the cupboard. This type of cupboard may be fitted with pull out shelves and is usually lipped to contain spillage. A removable collection tray in the bottom of the cupboard is provided to contain any excess spillage;

  Construction materials used for the storage of chemicals, solvent, acid and alkali must be considered carefully, particularly where spillage is likely to occur. All materials have some inherent weakness that causes it to react with the chemical resulting in corrosion, softening/dissolving, ignition/fire, toxic emission or simple mechanical failure. Common materials used include fiberglass, galvanized steel, stainless steel, polypropylene and glass — each selected for chemical compatibility and physical suitability.
- **controlled temperature**: Often in laboratory operations, it is necessary to store materials at low temperatures. This may be in refrigerator units with storage temperatures a few degrees above zero or freeze units providing sub-zero storage or at the extreme, cryogenic storage systems achieving $-83°C$. Each of these units may require floor space within the laboratory. Typically they are freestanding vertical units with a single door, internally divided into compartments with individual pullout trays. Temperature controls and displays are clearly visible on front of the units. Usually units are designed to suit a 600 mm module.

Operational considerations

(a) Laboratory equipment

The requirements for laboratory equipment will depend upon the procedures to be conducted within the laboratory. Laboratory procedures are generally analytical. The laboratory operator prepares a schedule of equipment with approximate sizes, which will indicate the safety considerations for each piece of equipment, specifying where fume hoods or fume cupboards are required to control emissions. The schedule may include useful information on service utilities for equipment, power, gas, water, air, etc., complete with loads, flowrates, and diversity figures. Typically the equipment includes:

- gas chromatographs (GCs);
- high pressure liquid chromatographs (HPLCs);
- rotary evaporators;

- ovens;
- furnaces;
- ultrasonic baths;
- balances.

Armed with this information it is possible to evaluate the basic quantity of furniture items required to satisfy the demands of the laboratory operation.

(b) Ancillary equipment

A host of equipment and storage facilities is required to support any laboratory operation. Guidance is required from the laboratory operator as to the most appropriate and essential items, but generally these will include:

- glassware washers and driers;
- refrigerators;
- freezers;
- safety station — eyewash and safety shower;
- water purifiers;
- vacuum pumps;
- gas generators or cylinders;
- all types of storage.

(c) Personnel and ancillary space

Laboratory operators undertake a number of functions within the laboratory and, whilst they may spend a lot of time at the workbench, they also need an area for report writing and filing. Outside the laboratory, facilities are required for personnel washing and changing, rest and recreation and archive storage of records and samples.

(d) Workflow

The definition of space requirements discussed above provides a quantitative analysis of space requirements for the laboratory. To begin to plan a laboratory into a useful layout requires an understanding of workflow.

The laboratory operator has the best understanding of workflow and work patterns within the laboratory. A simple flow chart or bubble diagram by the laboratory operator will ensure the laboratory design satisfies the demands of the busy schedule of activities in the contemporary laboratory.

Workflow should aim to be in one direction with necessary support facilities provided at each step. Back tracking and cross-over should be avoided as these dramatically increase the risk of accident.

Timing is important — analytical processes may take minutes or hours to complete. The slowest process dictates the throughput of the laboratory.

Workflow is improved by increasing the numbers of critical equipment items (subject to budget). 'Bottlenecks' should be identified and recorded.

Whilst it may be practical to provide utility services to all bench areas, costs aside, it is not always practical to provide additional space for process and utility activities in sufficient number to meet the demand; any limitation must be accepted by the laboratory operator.

Storage space is essential. Storage must be well distributed around the laboratory. Glassware and other implements should be readily available from a number of local storage units. Chemicals should generally be dispensed from a central safe storage location. Trolleys may be used to transport chemicals safely and as a mobile workbench. The laboratory layout must make adequate provision for safe parking of the trolley whilst it is in use as an extension to the work area.

(e) Material flow

Sample receipt, handling and storage feature highly in the work flow requirements for the laboratory.

Once a sample is received into the laboratory it is catalogued before being processed further. The sample is then dispensed into a number of units for different analytical procedures, each catalogued according to the batch requirements. All handling operations must be undertaken with due regard to safety, requiring the use of safe working practice and safety procedure. The use of adequate protective clothing and specialist equipment are essential. The laboratory design must make provision for storage of safety equipment, clean and dirty protective clothing. Changing facilities with showers may be required for some facilities. Clearly identifiable disposal units, segregated according to hazard are as important to safety as safe handling of materials. The laboratory operators must have reasonable access to a safety shower and eyewash facility.

The route for analytical procedures should be planned to be in one direction only, with no crossing of paths or doubling back. Consideration must also be given to the segregation of the different operations — for example, wet chemistry areas are designed to contain spillages and splashing whilst balances are often placed in separate rooms to minimize the effects of adverse room air turbulence and moisture.

(f) Work scope

In large laboratory buildings, different functions are undertaken in separate laboratory rooms, each with appropriate facilities and finishes. In major research complexes, individual laboratory buildings may be designed for different research areas including chemistry, biology, microbiology, biotechnology and animal research (which owing to its political sensitivity is more often referred to as Central Research Support Facility or Biology Support Unit).

There are many support functions which may be undertaken within laboratories such as small-scale production (for clinical trials), kilo labs, instrument and equipment calibration, dispensing and preparation of chemical additives (subject to regulatory restrictions), physical testing.

(g) Personnel flow

Laboratories are hazardous places. The high level of manual handling of dangerous materials, including flammable, toxic, corrosive, radioactive, carcinogenic, bacterial, viral and pathogen, place operators into potentially lethal environments. Whilst laboratories are generally restricted to small quantities of such materials, the consequences of an accident may not be confined to the laboratory, placing the environment and local communities at risk.

Whatever the risk or consequence, strict manual handling policies must be adopted. The laboratory designer must consider the philosophy when establishing the basic design and layout. Personnel need to be able to move around the laboratory freely without cause to disturb colleagues who may be undertaking hazardous operations (albeit with controlled conditions). The operator may also be required to manoeuvre a trolley or cart, carrying hazardous materials, around the laboratory. To ensure these functions are undertaken safely, adequate space must be provided between benches. Fume cupboards need to be positioned where operators have room to manoeuvre freely without being cramped by walls or other fixtures and clear from potential collision with other operators and mobile equipment. The diagrams in Figures 9.1–9.3 (pages 314 to 320) illustrate the general principles of spacing within a laboratory.

(h) Fume cupboards

The use of fume cupboards within a laboratory varies considerably depending upon the nature, frequency and duration of activities undertaken which are either hazardous or are susceptible to contamination. When considering what operations are undertaken within a fume cupboard, it is important to evaluate the viability of multi-function use. Where apparatus can be set up and dismantled in a relatively short time and frequency of use is low, fume cupboards may be utilized for a number of different activities. Keeping the number of fume cupboards low not only saves space and capital costs, it also aids HVAC design. Fume cupboards extract enormous volumes of air from the room. By the nature of a fume cupboard operation, this air must be exhausted to

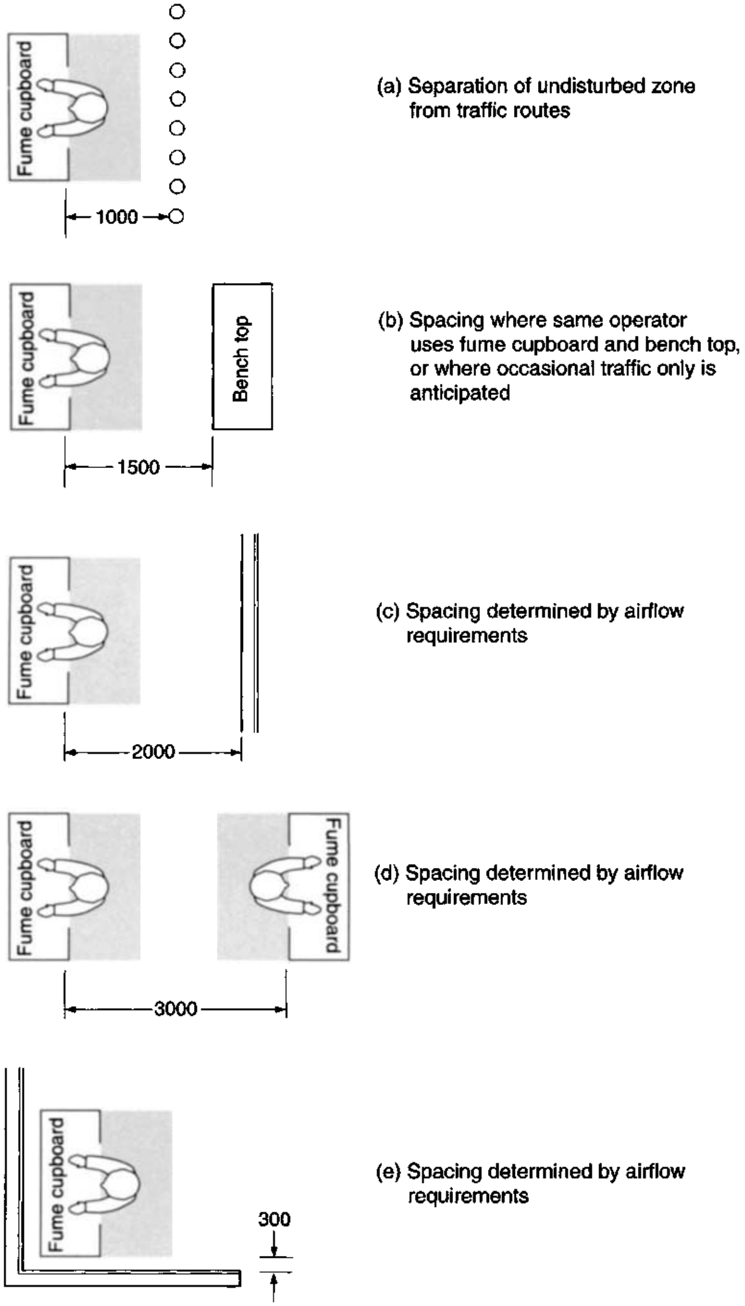


Figure 9.1 Minimum distances for avoiding disturbances to the fume cupboard and its operator

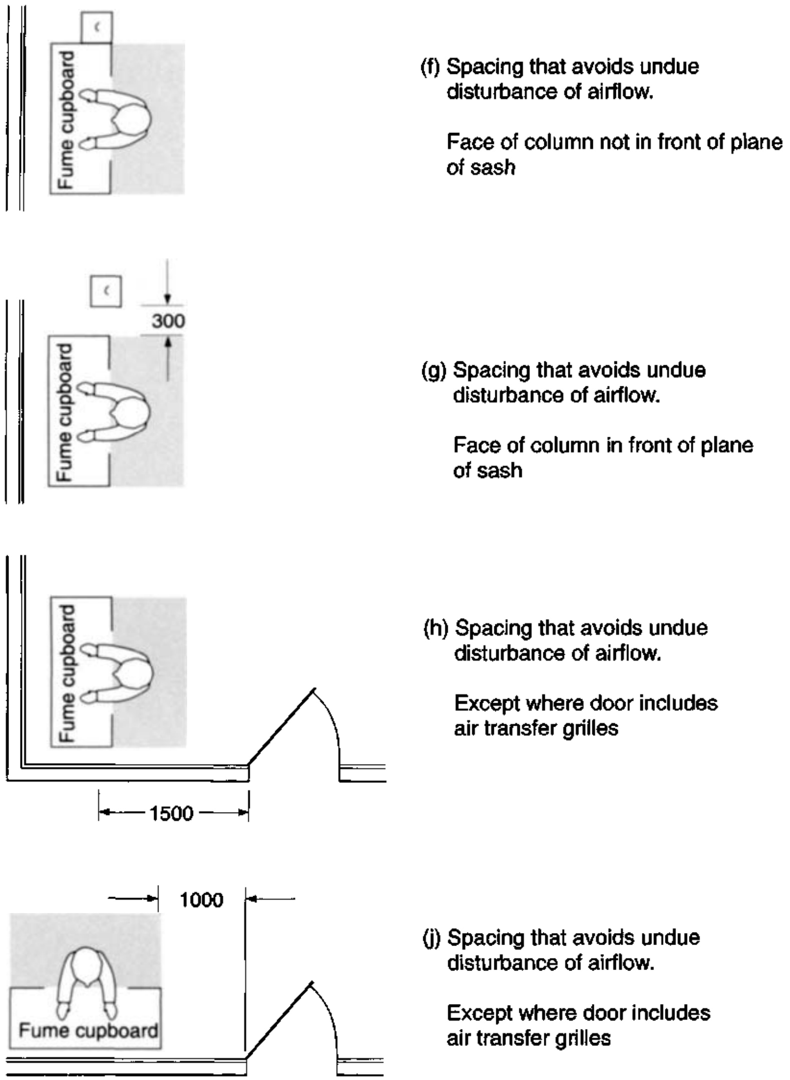


Figure 9.1 (*Continued*)

atmosphere. Detail on the design of air systems is discussed later in this chapter in Section 9.5.

There are a number of different types of fume cupboards available depending on operational requirements. The construction details of each are described

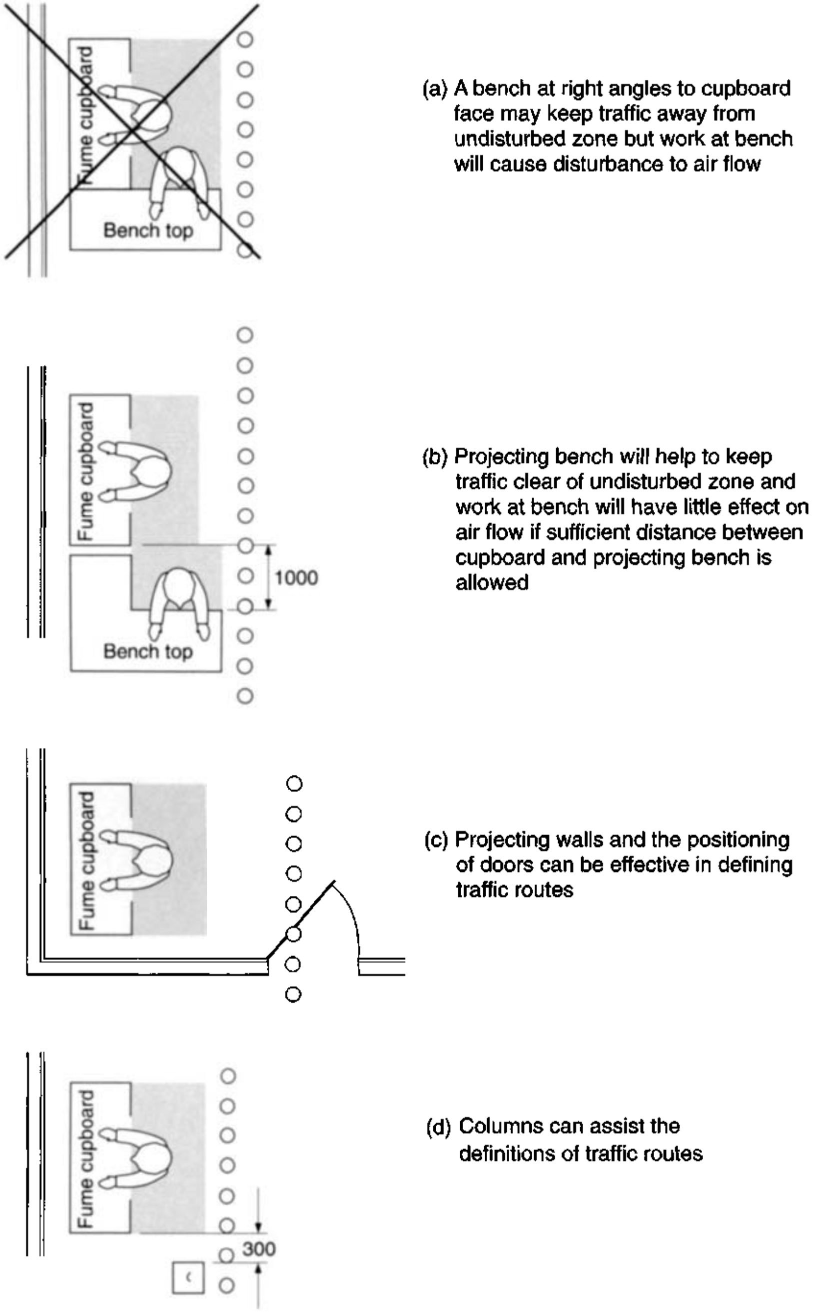
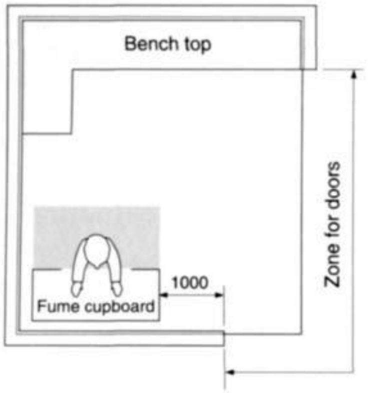
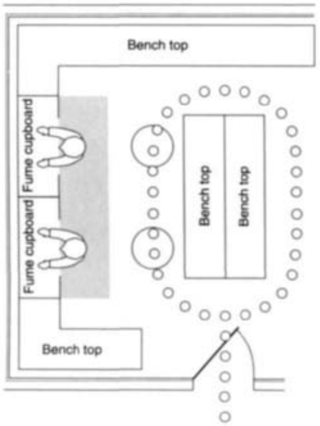


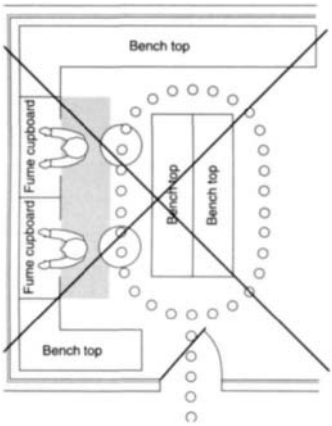
Figure 9.2 Planning arrangements for avoiding disturbances to the fume cupboard and its operator from other personnel



(e) In a small laboratory, the fume cupboard should be clear of personnel entering through doors



(f) Too much movement in front of fume cupboards should be avoided by providing more than the minimum distances between faces of fume cupboards and bench tops



(g) Too much movement in front of fume cupboards should be avoided by providing more than the minimum distances between faces of fume cupboards and bench tops

Figure 9.2 (*Continued*)

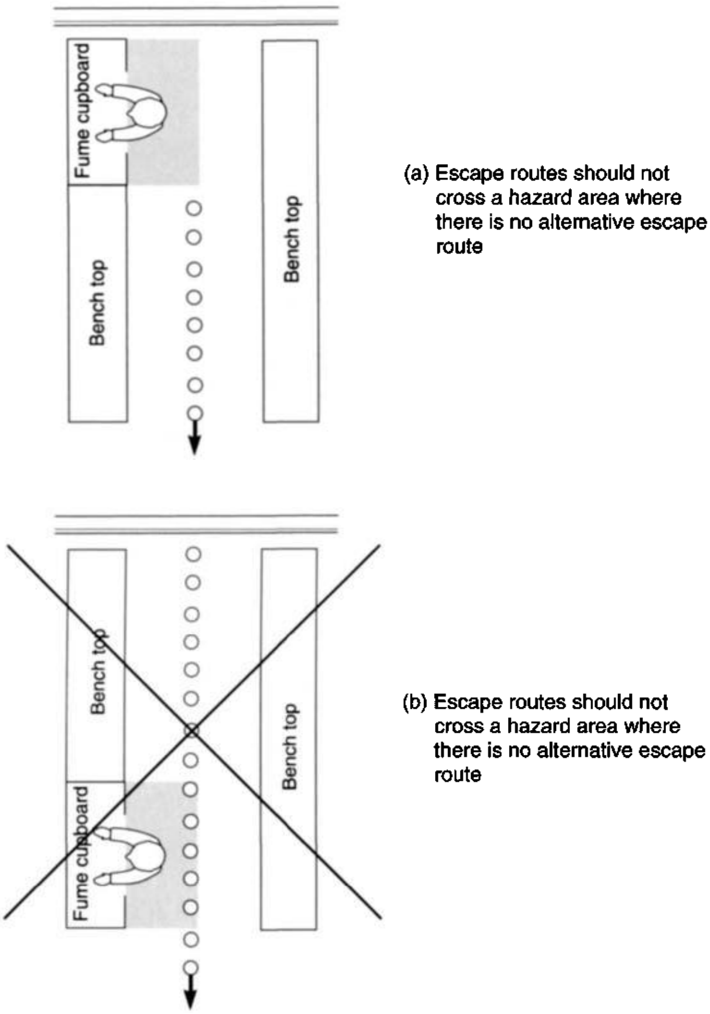
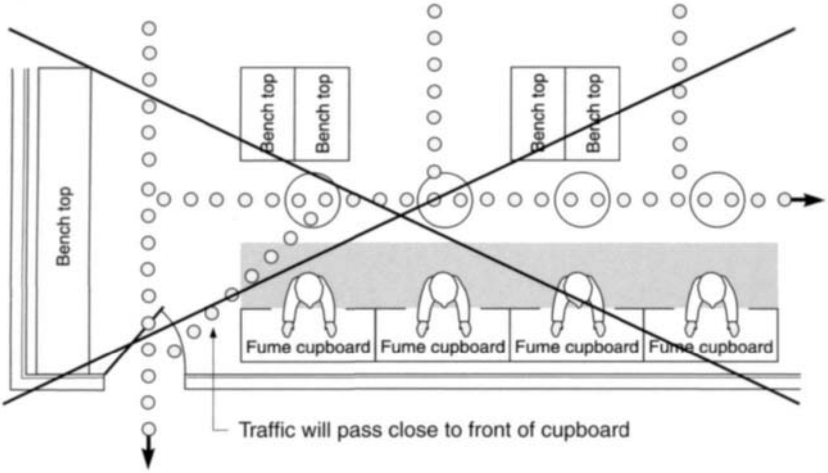


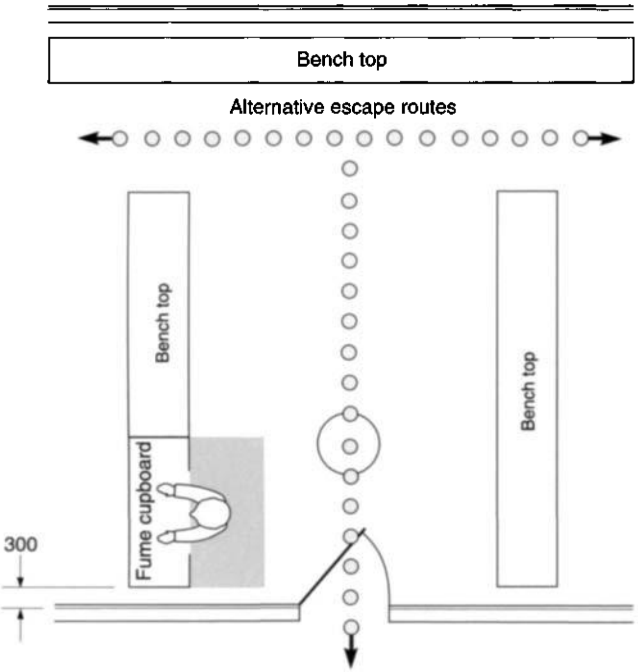
Figure 9.3 Escape routes

later in this chapter in Section 9.4. The principle selection criteria are summarized below:

- size: Generally available in modular widths to complement laboratory benches: 1200 mm, 1500 mm, 1800 mm, 2000 mm, 2100 mm are typical;
- sash: Sashes come in a variety of configurations, with vertical sliding being the most common. Horizontal sliding is restrictive but when

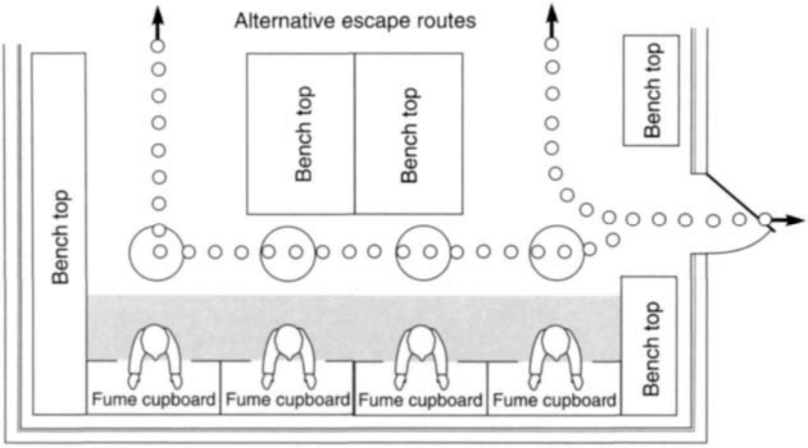


(c) Principle escape routes should not cross hazard areas



(d) Alternative escape routes should supplement an escape route that crosses a hazard

Figure 9.3 (*Continued*)



(e) Alternative escape routes should be provided from all hazard areas in laboratories with more than one fume cupboard

Figure 9.3 (*Continued*)

combined with vertical sliding it provides a more versatile arrangement. Large sashes are often split horizontally to limit travel and headroom requirements. Sashes normally start at bench top level. If large equipment is envisaged then a lower level is appropriate. Some fume cupboards are 'walk in' to accommodate large or heavy apparatus.

- safety: Most fume cupboards designs are intended to protect the operators from the hazardous materials being handled. This is achieved by creating a negative air pressure across the open sash face. The velocity across the face is usually measured at $0.5\,\mathrm{m\,s^{-1}}$ (termed face velocity). Maintaining the face velocity for a variety of sash sizes and opening heights is the fundamental design principle for fume cupboards.

  Other safety considerations are that the fume cupboard must offer protection to the operator from fire and explosion, both of which demand careful consideration in the selection of suitable construction materials. Details of construction are discussed later in Section 9.4.
- facilities: The function of the fume cupboard determines the nature and number of facilities. These will include utility and laboratory services such as power, water, air, gas, etc.; equipment frames; sinks and troughs etc. Details of all available services are included later in Section 9.6.
- air systems: Although air systems will be covered in depth further on in this chapter, it is worth mentioning that there are two fundamentally

different types of fume cupboard — those which extract all air and those which recirculate air. Recirculatory fume cupboards rely upon local filters to ensure a safe working environment is maintained. This type must only be used for low risk operations. Total extract type remove all air to atmosphere, thus, providing a safe working environment within the laboratory.

9.3 Furniture design

9.3.1 Bench construction systems

Figure 9.4 on page 322 illustrates some of the common bench construction systems.

Pedestal furniture

The pedestal system of benching provides a rigid bench construction by directly supporting the work surface on the underbench units of furniture.

The system is highly cost-effective and commonly features a wide range of modular size units to suit most installations. This pedestal system is an ideal solution in those applications where there is an infrequent requirement for underbench furniture to be interchanged, although should any changes be needed, they can easily be carried out utilizing the services of a maintenance department.

'C' frame bench construction system

This type of bench construction system is ideal for applications where flexibility in the choice of units is a requirement, together with a clear floor space for cleaning.

The system provides a rigid bench construction capable of taking heavy loads. It does not require any floor or wall fixings.

This type of system accepts both suspended and movable types of furniture. Also with both types of unit, the framing allows the units to be placed adjacent to one another without gaps.

Cantilever bench framing

Cantilever bench framing is ideal in installations where flexibility and ease of floor cleaning is required, as there is no horizontal floor leg to cause any obstruction. The design allows for suspended, movable and removable underbench units to be placed anywhere along the length of the benching and repositioned at any time without interference.

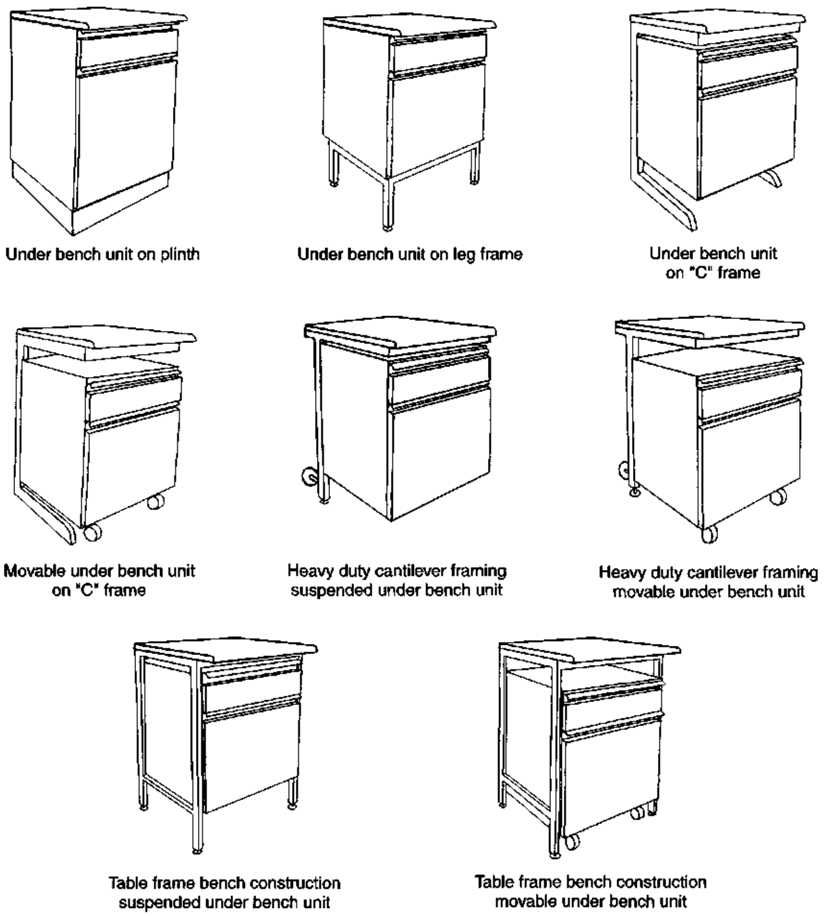


Figure 9.4 Laboratory bench framing and under bench units

Available as both standard and heavy-duty cantilever supports, each requires a degree of wall-support for any perimeter benching. Both types are also suitable for island and peninsular benches.

- standard cantilever framing: This system is designed solely for use with removable under bench units; the units themselves provide the necessary additional support to the worktop;
- heavy-duty cantilever framing: The alternative heavy-duty cantilever support system is manufactured from heavier steel sections and, although needing more robust wall and floor fixings, is suitable for movable and suspended underbench units.

Table frame bench construction system

The construction of the table frame is designed to offer both flexibility and economy. It is rigid and can accept heavy loads with minimum deflection. The design will accommodate either suspended or movable furniture units.

When used against a service spine accommodating the mechanical and electrical outlets, further flexibility may be achieved by using modular table units, which obviate the need for long runs of benching. Table frames are generally fitted with adjustable feet for levelling.

Tall storage cupboards

A wide range of tall storage cupboards is available:

- acid/alkali cupboard;
- solvent storage cupboard;
- safety cabinet;
- storage cupboard with pull-out shelves.

Accessories

A large range of integrated accessories is available, such as a comprehensive range of drawer dividers.

9.3.2 Bench top materials

There is a varied range of bench top material available to suit any application. Materials are extensively tested. The most popular materials are detailed below, but this is by no means an exhaustive list. Sizes quoted are typical for the material. The suitability of each material for use with a range of chemicals is summarized in Table 9.1.

Laminate

These bench tops have a thickness of 30 mm. They are covered with laminate with a rolled front edge and bonded to a high-density particle board base. All ends are sealed with a 4 mm thick edging strip of polypropylene.

Epoxy resin

Epoxy resin tops are manufactured from solid epoxy resin and are self-supporting. The tops generally have a thickness of 15 mm, with a dished edging strip 10 mm high, giving a 25 mm thick edge; an alternative is available with a thickness of 19 mm with a 6 mm raised edge.

Table 9.1 Chemical Resistance Chart

	Kambala Iroko	Melamine Laminate	Solid Grade Laminate	Stoneware	Epoxy Resin	Stainless Steel	Tiles	PVDF	PP	PVC	Glass	Slate	Linoleum
ACIDS													
Sulphuric	■	□	□	●	○	○	●	●	●	●	●	○	○
Hydrochloric	○	○	○	●	●	■	○	●	●	●	●	○	○
Fuming Nitric	■	■	■	●	□	■	●	●	●	●	●	□	■
Perchloric	■	□	□	●	●	□	●	●	●	●	●	□	■
Nitric	■	□	□	●	●	□	○	●	●	●	●	□	■
Chlorine	□	○	○	●	●	□	●	●	●	●	●	●	□
Hydrofluoric	■	□	□	○	○	□	●	●	●	○	○	□	■
REAGENTS													
Ammonia	○	●	●	●	●	●	●	●	●	●	●	●	○
Sodium Hydroxide	○	○	○	●	○	●	●	●	●	●	●	○	○
Silver Nitrate	□	□	□	●	○	●	●	●	●	●	●	○	○
Potassium Permanganate	○	○	○	●	○	●	●	●	●	●	●	○	○
Iodine (in 15% Potassium Iodide Soln.)	○	○	○	●	○	●	○	●	●	●	●	○	○
Bromine	□	□	□	●	□	□	○	□	□	□	●	□	□
STAINS													
Malachite Green	○	○	○	●	○	●	○	●	●	●	●	○	○
Crystal Violet	○	○	○	●	○	●	○	○	○	○	●	○	○
Carboxy Fuchsin	○	○	○	●	○	●	○	●	●	○	●	○	○
SOLVENTS													
Acetone	○	●	●	●	○	●	●	●	●	○	●	●	○
Toluene	○	●	●	●	●	●	●	●	●	○	●	●	○
Methyl Alcohol	○	●	●	●	●	●	●	●	●	●	○	●	○
Carbon Tetrachloride	○	●	●	●	○	●	●	●	●	○	●	●	○
Diethyl Ether	○	●	●	●	○	●	●	●	●	●	●	●	○

● = No effect
○ = Slight staining after wiping surface clean
□ = Severe staining and potential corrosion after prolonged use
■ = Not suitable

Solid grade laminate

These tops are normally fabricated from 20 mm thick boards with the edges cut square and polished. Alternatively the front edge can be radiused and polished.

Solid wood

These tops are generally available in Iroko, Kambala or Beech with a thickness of 25 mm or 30 mm. They are constructed from narrow boards jointed with special 's' joint and waterproof glue. They can be linseed oil finished or varnished.

Stoneware

The tops are of solid acid-resistant, glazed stoneware. All tops have a thickness of 30 mm, with a raised front edge 7 mm high. End edging strips of Polybutylene Teraphthalate (PBTB) are available for protection and dishing of ends.

Stainless steel

Two types of stainless steel top are normally available either bonded onto a wood core or self-supporting with suitable reinforcing on the under side. Tops are usually manufactured from Type 316 acid resistant stainless steel. The standard construction is either flat with an overall thickness of 25 or 30 mm, or with a raised edge with a thickness of 32 or 37 mm.

Tiles

Tiled worktops are manufactured utilizing a laminated board base, with all surfaces double-sealed with epoxy resin. First grade chemical-resistant tiles are bonded to the base and jointed with chemically resistant cement to an epoxy grout.

These tops are available as flat worktops or with a raised edge. Flat tops have a thickness of 30 mm. Raised edge tops have a thickness of 37 mm.

Plastic veneered

Plastic veneered tops are available in three types of veneer:

- polyvinylidene fluoride (PVDF);
- polypropylene (PP);
- polyvinyl chloride (PVC).

All tops are covered with one of these materials bonded onto a high density chip board core, with either a flat edge, or with a raised edge all round. In the latter case, the special raised front edge section is welded to the work surface and taken down from the front edge.

Flat tops have a thickness of 30 mm. The raised front edge has a thickness of 37 mm.

Slate

Slate bench tops are used almost exclusively for balance benches. High quality tops are of Welsh Blue Slate with polished edges and thickness of 25 mm or 30 mm.

Glass

These tops are manufactured from a core of block board, covered on both sides with white melamine laminate and veneered with 6 mm thick glass. The toughened glass top surface may be acid etched to give a matt finish. These tops are usually available either flat with a front plastic edging strip in a cumulus green colour or dished with a plastic edging profile. All joints are sealed with silicon rubber sealant.

Linoleum

These tops are manufactured from a core of block board, edged with an insert of heavy-duty linoleum. The tops have a thickness of 25 mm or 30 mm.

Chemical resistance chart

Table 9.1 (see page 324) shows the chemical resistance, at specific concentrations, of the materials used for bench top surfaces and fume cupboard liners. Note that it is only intended to indicate the possible effect of the more commonly used acids, reagents, stains and solvent. It is not intended as a fully comprehensive guide.

9.3.3 Service spine systems

A wide variety of service spines are available, ranging from conventional box spines through to different types of flexible multi-service spines and modules to suit specific applications.

Bench mounted box service spines

Commonly manufactured from melamine faced board with all exposed edges veneered in polypropylene or similar. All electrical outlets are mounted onto the vertical front fascia while mechanical services and drip wastes (if required) are positioned on the top fascia. Where necessary, reagent shelves can also be fitted to these spines.

Floor mounted box service spines

Floor mounted service spines offer the advantage of flexibility; loose benching may be positioned up to them and not necessarily attached. Also, all services can be installed and tested prior to final bench installation.

All spines are supported from an angle iron framework, which accommodates the mechanical service pipework, electrical conduit and cladding panels.

Flexible, multi-service spine system

This is a pre-fabricated self-supporting spine. Consisting of a metal section, with adjustable feet, it can accommodate and support a number of different mechanical services and waste lines.

For maximum flexibility, a capping strip may be fitted at bench level. Alternatively, where flexibility is of minimal concern, the work surface can be taken flush to the spine.

Situated above the work surface is the mechanical service strip, generally made of solid grade laminate, which can either be of a closed type — the strip being taken down to worktop level — or of an open module design which allows a gap above the worktop.

Trunking for electrical outlets is usually above the mechanical services. Over this, trunking may be height adjustable reagent shelves specified in glass, melamine laminate or solid grade laminate. The reagent shelf support may also incorporate scaffold supports suitable for small diameter rods.

Designed in modular lengths to suit most applications, all services are pre-installed in the factory enabling pressure testing to be undertaken before dispatch. Thus, on-site installation time is minimized because it is only necessary to make the joints at the module ends.

Compact, multi-service module

A multi-service module allows for a high-density distribution of mechanical and electrical service outlets.

This type of module is suitable for use as a service bollard with either table frames or mobile trolleys placed against it (an ideal situation for analytical instrumentation) or, alternatively, mounted above a wall bench to provide a high density of outlets in a limited space.

A further use of this module is to site it between two fume cupboards. This enables services to be supplied to both cupboards from a single source and obviates the need for service outlets to be sited in the fume cupboard itself.

Typically, the module is fabricated from moulded sections with a lower section accommodating the mechanical services and the top section housing the electrical outlets. Intermediate sections can be added to accommodate additional mechanical services or outlets for clean instrument gases. The service feed pipes for these modules can either be sited overhead or below. Suitable cladding panels may be used to conceal these service pipes.

Overhead service boom

The use of the overhead service boom, in conjunction with mobile tables, ensures that maximum flexibility is achieved in laboratory benching layout. When used with standard benching, all services are supplied from the boom, leaving the work surface completely free for apparatus and instrumentation.

Booms are available single-sided for wall benches and double-sided for island/peninsular benches.

Boom frames are constructed from metal sections to accommodate the mechanical service outlets with electrical trunking above for 13 amp electrical outlets. Solids grade laminate panels are fitted as a closure to the bottom of the boom. Double-sided booms may be fitted with guardrails at the bottom.

The units are suspended from the soffit on uprights fitted with mounting plates. Services are supplied to the boom from overhead and may be enclosed in a dropper box.

9.3.4 Balance and instrument benches

Balance benches

These benches are specially designed to support analytical balances and other sensitive instruments.

Benches are usually constructed from heavy-gauge steel sections and fitted with adjustable feet. The framing supports, via anti-vibration pads, an anti-vibration work surface consisting of a heavy, thick terrazzo plate. The whole metal structure is often clad in a separate melamine veneered enclosure to give additional protection.

Instrument benches

These are compact benches specifically designed to house analytical instruments together with associated computer and printer equipment.

Benches are based on mobile trolleys fitted with two fixed and two lockable castors. Uprights are fitted to the back of the bench to accommodate the cable store, removable cladding panels, electrical and mechanical services, shelf and swivel monitor stand.

Typically, a melamine laminate worktop is included, under which may be housed additional units, fitted with either cupboards or drawers or a pull-out writing flap or pull-out shelves.

Electrical and mechanical services (such as instrument gases) are connected to the bench from socket and service outlets on adjacent benches via flexible cables and service pipes.

9.3.5 Tables and trolleys

Tables

Two types of table frame are available: the 'C' frame support and the 'H' frame support. Both types are available in various lengths, depths and heights, or in continuous runs to suit specific applications.

The 'C' frame table support

This is normally manufactured from rectangular steel with connecting rails. The cantilever support is fitted with adjustable feet for levelling. Tables are usually fitted with melamine laminate worktops or with other materials. According to availability 'C' frame support tables are designed to carry a limited load.

The 'H' frame table support

The leg frames are usually manufactured from rectangular steel sections, are of welded construction and are fitted with levelling feet. Longitudinal rails are also steel section. Tables are commonly supplied with melamine laminate tops but any other materials may be specified.

Trolleys

These trolleys are typically manufactured as for 'H' frame tables but are fitted with double-wheel castors equipped with rubber tyres, one diagonally opposed pair of castors being lockable. These trolleys are fitted with melamine laminate worktops and shelf, and have a good load carrying capacity. Other worktop materials are always an option.

9.4 Fume cupboards

When considering the layout of a laboratory, the design and positioning of fume cupboards is of critical importance. Poor design or bad positioning of a fume cupboard is not only a safety hazard, but it can detract from the working environment (see Section 9.2 on planning a laboratory).

9.4.1 Typical fume cupboard construction

Support system

Fume cupboards can be supported on pedestal unit furniture, cantilever 'C' frames or table frames with suspended or movable units of furniture. Frames are usually of epoxy powder coated rolled hollow section (RHS) mild steel.

Carcass materials

Mild steel frame sections are commonly used to support external panels of epoxy powder coated steel or compensated laminate-faced medium-density fibre board. (In compensate laminate a balancing laminate is applied to the hidden inside face to prevent exposed facing laminate distorting the board).

Top cover access panels

Designed to be easily demountable, top cover panels may be either epoxy-coated steel or laminate finished board to match fume cupboard outer panels.

Basic internal construction

The back panel is constructed from solid grade laminate, whereas the side and top panels are melamine-veneered boards. Generally the top panel has a cut-out fitted with laminated safety glass, complete with a removable light cowl and light tube. Explosion flaps may also be fitted in the top panel.

A back baffle of solid grade laminate is specifically designed to give an even face velocity. It should include slots to ensure good scavenging at the sides and at the back corners of the cupboard. Scaffold points may be fitted to the back baffle.

Sash design

The vertically sliding sash is commonly made of toughened or laminated safety glass in a metal frame with profiles finger pull to improve airflow characteristics at the lower edge. Suspension is usually by stainless steel cables and lead counter balance weight, the cables running over ball raced nylon pulleys, all arranged on a fail-safe principle in the event of cable failure. Sashes may include horizontal sliding side sashes within the vertical sash frame or horizontally split sashes used where a limited room height restricts normal sash operation.

Airflow

Either a by-pass is fitted above the sash to reduce the face velocity at the lower sash openings and to give a constant extract volume, or a microswitch is fitted to signal the extract system to reduce the extract volume by way of an actuated damper or variable speed fan motor. A profiled metal sill fitted at the front of the work surface ensures good low-level extraction.

The top of the cupboard should be fitted with an aerodynamically designed take-off manifold of fire resistant polypropylene, or similar, ready for connection to the extract system. The manifold should include a condensate collar and, if necessary, a condensate drain.

Utilities

Service outlets are fitted on the centre back wall or the side-walls of the cupboard with control valves fitted into a front fascia rail which also accommodates the electrical outlets. Alternatively, controls may be located on each side of the fume cupboard. Refer to Section 9.6 for details of the services available and distribution systems.

9.4.2 Fume cupboard liner and baffle materials

There is no single, practical construction material for fume cupboard liners that is suitable for all reagents. A comprehensive range of construction materials is available, with each suited to the specific use to which the cupboard is to be put. See Table 9.1 on page 324 for material selection guide.

Liners and back baffle materials

- melamine: veneered high-density board;
- duraline: modified resin and fibreglass filled sheet;
- solid grade laminate;
- polypropylene;
- PVC;
- stainless steel — Grade 316, natural finish;
- toughened glass with backing.

Melamine veneered high-density board

This is highly suitable for use as a construction material for side and top panel. Careful consideration must be given to the detail design and construction of the cupboard to ensure that exposed sides or ends do not come into contact with fumes.

This material is only suitable for general-purpose fume cupboards. It is not suitable for use with perchloric acid, radio-isotopes or cupboards which have heavy duty acid use, i.e., metallurgical digestion cupboards or those fitted with a water wash facility.

Duraline

A cost-effective, modified resin and fibreglass filled sheet designed to have good flame retardance, mechanical strength and chemical resistance.

Solid grade laminate

This can be used either for the construction panels of the cupboard, utilizing a thick board, or for the lining panels and back baffles, requiring a reduced thickness board.

This material is very suitable for general-purpose fume cupboards and for cupboards used in low-level radio-isotope applications. It is not suitable for perchloric or heavy acid use.

Plastic

Polypropylene or PVC liners and back baffles are typically fabricated from 16 mm thick material. The plastic liners are excellent for fume cupboards used predominantly for heavy acid applications. Some solvents will cause the plastic to soften. However, once the solvent has evaporated, the plastic will usually appear unaffected. The disadvantage of these liners is their relatively low temperature tolerance. PVC softens at 60°C and polypropylene at 90°C.

If electric hot plates are used in fume cupboards with these types of liner, the power supply should only be energized once the extract fan is switched on. If gas hot plates are used, a solenoid should be fitted in the supply line to inhibit the use of these hot plates when the extract fan is switched off. The fan minimizes the effect of radiant heat on the plastic liners.

Stainless steel

Stainless steel liners are manufactured from acid resistant (Grade 316) stainless steel. They are normally available as either fabricated sectional liners with joints sealed with silicon rubber or one-piece liners and worktop with all corners radiused for ease of cleaning. Care should be taken in selecting this material for specific applications as stainless steel is, to some degree, affected by acids (see Table 9.1 on page 324).

When used for acid applications i.e. perchloric acid including Kjedahl digestion, these fume cupboards should be fitted with water washing jets to enable washing away of any condensed acids after a series of experiments.

Stainless steel fabricated liners are suitable for use in low-level radio-isotope applications. For higher-level use, one-piece liners should be specified.

Epoxy resin liners

Solid epoxy resin liners are generally fabricated from 6 mm thick epoxy resin sheets. All joints are sealed using epoxy resin grout. These liners are suitable for general-purpose fume cupboard use and for high acid use. Some staining may occur when they are used for concentrated acid applications, although the base material normally remains unaffected. Some solvents may also affect this material (see Table 9.1 on page 324).

9.4.3 Fume cupboard work surface materials

Fume cupboard work surfaces may be selected from the higher specification range of bench top materials where chemical resistance and the ability to provide an integral raised rim are important selection criteria.

Work surfaces

- solid epoxy resin;
- solid grade laminate;
- stainless steel — either heavy gauge with reinforcing on underside or light gauge with all edges turned over and under and bonded to a WBP plywood base;
- quarry tiles — on WBP plywood base, bedded and pointed with acid resistant cement;
- polypropylene — bonded to a WBP plywood base.

It is advisable to incorporate raised edges to work surfaces to contain spillage.

9.4.4 Fume cupboards for specific purposes

Fume cupboards for use with some specific reagents or for certain types of analysis require special consideration. Detailed below are cupboards designed to meet some of the more common of these applications.

Fume cupboards used for Kjeldahl digestion

Due to the problems of both heat and condensed acid, either stainless steel or polypropylene liners should be used. Ideally, the necks of the Kjedahl digestion flasks should be manifolded together to enable the majority of the acid fumes to be extracted via a water vacuum pump — the fume cupboard only being used as a secondary containment device. Alternatively, a proprietary digestion apparatus, incorporating its own heater and local extraction may be used.

Polypropylene liners give the best chemical resistance and are quite acceptable if electric heating mantles are used. However, if Bunsen burners are used, care must be taken not to overheat or burn these liners. It is good practice to have a solenoid valve in the gas supply line energized by the extract fan motor. This inhibits the use of the gas burners without the extractor fan switched on.

For both liner materials, it is desirable to fit a water wash device in the cupboard to facilitate washing down after a series of digestions.

Fume cupboards for use with perchloric acid

Fume cupboards designed for this use should be fitted with either stainless steel or polypropylene liners. When stainless steel liners are used, there can be a certain amount of acid attack on this material; however, the by-products of this corrosion are safe and their presence can be minimized by the frequent use of the water wash system. The disadvantage of propylene liners is that when perchloric acid is used, it is normally heated and the heat generated can cause distortion of the plastic liner. Therefore, care must be taken to ensure that the heat source is not placed too near the sidewalls or back baffle.

Due to the possibility of explosive perchlorates being formed by the condensed acids, the fume cupboards and associated duct work should be fitted with water wash jets to enable the system to be washed down after a series of experiments.

Consideration should also be given to fitting a fume scrubber immediately adjacent to the cupboards before the main fume extraction ductwork so that any condensed acid can be washed out. If this is done, then the ductwork after the scrubber will not need to be fitted with the water wash jets.

Fume cupboards for use with hydrofluoric acid

If significant quantities of hydrofluoric acid are to be used (and evaporated), the fume cupboard should be fitted with polypropylene liners. The cupboard should also be fitted with either a water wash system to enable washing down of any condensed acids after a set of experiments or with easily removable baffles to enable manual washing of the inside of the cupboard.

Additionally, the extract system should be fitted with a fume scrubber, either adjacent to the cupboard or on the roof before the extract fan, to inhibit fluorides being emitted into the atmosphere. It should also be remembered that because of etching, the sash should be made of plastic i.e., clear PVC or polycarbonate, rather than glass.

Fume cupboards for use with radio-isotopes

When considering fume cupboards for radio-isotope work, several factors which affect design need to be taken into account. These include the isotope's level of activity, its half-life, the need for filtration and the suitability of the cupboard's face velocity.

If the cupboard is only to be used for tracer work, standard solid grade liners with a face velocity of $0.5\,m\,s^{-1}$ may be suitable. For dilution work or high levels of activity, the fume cupboard may need a one piece welded liner of stainless steel together with an extract system fitted with high efficiency particulate air (HEPA) filters. Carbon filters may be required for some work.

9.4.5 Special design fume cupboards

Low-level fume cupboards

Low-level (distillation) fume cupboards allow work requiring tall items of equipment to be carried out. The sash opens to the full height of around 1800 mm.

Normally two proportionally opening sashes are fitted. Both are interconnected and operate on a fail-safe principle. Services are supplied to the cupboard from either an adjacent multi-service module or from a service fascia strip built into the underbench unit.

Walk-in fume cupboards

Walk-in fume cupboards provide an especially large workspace with a clear inside height of around 2100 mm and cupboards that are usually fitted with two independently movable front sashes. Sashes are steel-framed with the upper one often being fitted with two horizontal sliding sashes.

Frequently the standard cupboard sides are fitted with access ports with top hung flaps to allow cables and hoses to be passed through from adjacent multi-service modules. Alternatively, front fascia panels are fitted to house the mechanical and electrical controls with the mechanical outlets fitted to the sidewalls of the cupboard.

Special application fume cupboards

This fume cupboard is specifically designed for heavy duty, aggressive chemical use, such as for acid digestions where the significant amounts of condensed acids produced could affect the life of conventional cupboards.

Ideally, the cupboard is fitted with a two-piece, angled back baffle that is easily removable to allow decontamination and cleaning of the whole interior of the cupboard. The baffle is designed to give one third of the total extract volume extracted from the lower baffle opening and two thirds of the extract volume extracted through the top baffle opening. The internal configuration of the cupboard combined with the baffle openings ensures that fumes generated within the cupboard are first directed towards the lower baffle opening, then the fumes migrate up and adjacent to the back baffle and are extracted via the top baffle opening. The baffle is fitted with a condensate trough at the bottom with connection to drain.

While the carcass and sash construction of this cupboard is generally the same as basic models, the special application cupboard and its back baffle should be lined with approximately 5 mm thick ceramic, the top panel of solid grade laminate and the sash of laminated safety glass. For hydrofluoric acid use, the cupboards need to be lined with polypropylene and fitted with an aluminium back baffle that is polyamide-coated. Polycarbonate is recommended for the sash.

The special application fume cupboard should be specifically designed to accommodate a scrubber/demister unit for the removal of contamination from the extract air system before discharge into the atmosphere, especially important where perchloric or hydrofluoric acids are used.

9.5 Extraction hoods

Local bench extraction hoods

For many types of operation, where only small amounts of noxious fumes (smoke, vapour, gases) or occasional high temperatures are generated, local extraction at source is ideal.

A local bench extraction hood uses laboratory supply air to produce a cone-shaped vortex within its confines to capture any noxious substances and extract them efficiently and quickly.

Hoods may be fabricated from PVC or epoxy coated steel or stainless steel. It is important that the maximum height of a hood, above the source of emissions, should not be greater than its diameter.

A variable speed axial flow fan for supplying air from the laboratory may be mounted at the back of the casing, or the hood may be ducted to a central extract system.

Drop front steel extract hoods

Hoods are generally fabricated from steel and finished in epoxy powder coated paint. They normally have a vertically adjustable front cowl and are suitable for extracting radiant heat from ovens, muffle furnaces etc.

Chromatography spray hoods

These hoods are usually fabricated in PVC and are specifically designed for the spraying of chromatography plates. They are fitted with a louvred back baffle to give good extraction, and also with chromatography plate holders.

The hood is suitable for wall mounting or can be fitted at the rear corner of a fume cupboard. It is advisable for the extract duct to be flexible enabling the hood to be lowered during use or pushed up out of the working area of the fume cupboard when not in use.

Fume hoods

Fume hoods are available fabricated from epoxy powder coated steel, aluminium, PVC or polypropylene. They are available in a wide variety of styles to suit individual requirements. These hoods may be fitted with internal baffles to produce a high velocity peripheral extraction in order to improve containment. They may also be fitted with side and back panels.

9.6 Utility services

Services may range from simple installations, requiring just hot and cold water, drainage and possibly natural gas, to more sophisticated installations which use high-quality instrument gases.

Service pipework may be carried out both in-factory, using pre-plumbed service spines or by traditional plumbing methods with the pipework being battened to the wall or clipped to the furniture units.

9.7 Fume extraction

One of the most important areas of laboratory design is in the design and engineering of fume cupboard extract systems. No matter how good the design of the fume cupboard itself, safe containment remains critically reliant on the performance of the extract system. Not only must the system achieve the correct volume flow required for a particular cupboard or cupboards, consideration must also be given to noise, condensate drainage and to ensuring that ductwork does not contravene fire regulations.

Design criteria

Extract systems should be designed to provide a maximum duct velocity of $5–6\,m\,s^{-1}$. This velocity is sufficient to ensure good scavenging of the duct in order to inhibit any build up of contamination within the duct, whilst not being high enough to generate undue air noise within the ducting system. Generous radius moulded bends are recommended in all systems up to 600 mm diameter. Rectangular ductwork, and circular ductwork above 600 mm diameter may have fabricated bends.

Careful consideration should be given to the routing of all ductwork, so that it is taken outside the building, or to a firebreak service void, by the most direct route. Horizontal ductwork is to be minimized; where long runs are necessary, they are to be laid to a fall with a condensate drain at the lowest point. All extract systems, whether they serve a single cupboard or several cupboards (in which case a manifolded system may be used subject to safety criteria), require volume control dampers (butterfly type) to be fitted for system balancing. Normally all joints in ductwork are solvent welded socket and spigot type. If required, flanged ductwork, with Neoprene gaskets may also be specified for particular applications.

Materials of construction

The most commonly used ductwork material is UPVC, which is suitable for most applications. Where necessary, due to fire regulations, this ductwork can be GRP-coated to give 30–60 minutes' fire resistance, negating the requirement for fire dampers that introduce an additional safety hazard. For very specific applications stainless steel or galvanized steel ductwork is available.

Fume extraction fans

Fume extraction fans are fabricated from either UPVC or polypropylene. Fans should be generously sized to enable the impeller speed to be kept to a minimum for quiet operation. Flexible sleeves are recommended to isolate the fan for connection to ductwork.

Multi-vane forward curved blade type impellers provide maximum efficiency. They may be either directly driven or with indirect drive via 'V' belts and pulleys.

Motors with either single or three phase supply are available depending mainly on the load. Motors should be suitable for external use, as most installations find fans mounted on the roof.

Typically a fan unit is mounted on a galvanized steel angle frame complete with anti-vibration mounts.

9.7.1 Specialized ancillary equipment

Fire dampers

In those situations where it is sometimes necessary for ductwork to pass through firebreak walls or into general purpose building service ducts, it may be necessary to fit fire dampers. Fire dampers must provide the same corrosion resistance as the ductwork. Consequently fire dampers are usually fabricated from a stainless steel outer casing fitted with a stainless steel folding curtain shutter.

The shutter is fitted with stainless steel constant tension closure springs and is held open by a fusible link which releases the shutter in the case of fire. The fire damper is fitted into the partition wall and access hatches are provided in the ductwork for maintenance and testing. Owing to complex routing requirements or simply the sheer quantity of individual ducts, the configuration of fire dampers often makes it impossible to provide accessible access hatches. In these cases, motorized dampers provide an acceptable alternative.

Water wash systems

For some applications, such as extract systems handling perchloric acid, it is necessary to fit a water wash system. Spray jets are fitted into the ductwork, spaced approximately at a 1.5 metre pitch on vertical ductwork and at a 1 metre pitch for horizontal runs. Jets may be manifolded by a plastic supply pipe and controlled from a valve on the fume cupboard.

It is important to note that a water wash system should only be used for washing the ductwork and removing any condensed acids after a series of experiments. It should not be used during a series of experiments as the spray will contaminate the experimental work. A booster pump may be required if the head of water is not sufficient for the higher jets to operate satisfactorily.

Fume scrubbers

For those extract systems handling perchloric or hydrofluoric acid, fume scrubbers may well be needed. Two types of fume scrubber are generally available — the compact scrubber/demister unit and the tower scrubber.

In the case of perchloric acid, the compact scrubber/demister unit is ideal as it can be fitted adjacent to the fume cupboard. Therefore, all ductwork from the outlet of the scrubber will remain uncontaminated and water washing will not be required. This scrubber can also be used for hydrofluoric acid applications.

The compact scrubber/demister unit is only suitable for connection to single fume cupboards. Where larger volumes of extract air are to be handled, from several cupboards, then a tower scrubber must be used.

Fume scrubbers are normally fabricated from UPVC and, in the case of tower scrubbers, feature GRP reinforcement. All scrubbers comprise three sections:

- the holding or capacity tank for the scrubbing media;
- a packed scrubbing section fitted with wash jets;
- a demist section to remove the washing media before discharge into the extract system.

The installation requires a circulating pump provided with a water supply with a ball valve fitted, together with drain connection.

9.7.2 Air input systems

A factor sometimes overlooked in fitting out a new laboratory is that fume cupboards extract a considerable volume of air from the laboratory area. In non-ventilated laboratories without sealed windows, it may not be necessary to install an air input system if there are only a small number of fume cupboards, as approximately six to eight air changes per hour can be achieved within the laboratory by natural leakage. In modern laboratory blocks with well sealed windows or in those where there are large number of fume cupboards, consideration must be given to the installation of an air input system. In this instance, care must be taken in the siting of the actual input grilles so that turbulence at the fume cupboard face is minimized. As a general principle, no input grille should be within 1.5 m of the face of the fume cupboard.

Ideally, the input grilles or slot diffusers should be on the opposite side of the laboratory to the cupboards in order to 'wash' the laboratory with clean air. The use of grilles or slot diffusers is suitable to achieve room air change rates of up to 20 per hour. If the air change rate is above this, then a perforated ceiling grid should be used.

9.8 Air flow systems

9.8.1 Air-handling for the laboratory

Air management control systems, which when considered at the planning stage of a laboratory, provide economies in both capital investment and operational costs. Variable airflow reduces the entire air requirements which as a result enables the building ventilation system to be designed smaller, thereby reducing investment costs. Operational costs are minimized through continual adjustment of the air flow to meet the current working situation. The rate of all supply and extract air may be computer controlled to optimize plant operation providing lower energy consumption and the opportunity to introduce diversity factors to reduce capital and operational cost.

Construction and components

(a) Airflow controller

The airflow controller is a processor which monitors and regulates the volume of extract air depending on the position of the sash. Upper and lower nominal limits are established for the open and closed sash positions. For all other sash positions the air flow rate is determined as a linear function.

A sensor constantly measures the air volume and adjusts a damper when variations occur until the present value is achieved. The sensor is placed in a bypass system to protect it from aggressive fumes.

Most airflow controllers can be switched to different operational modes: normal operation, night operation (lower amount of air) as well as emergency operation (maximum amount of air with fully opened damper). They can also be provided with volt-free contacts for connection to a building management system (BMS).

(b) Sash controller

The sash controller is a processor responsible for closing the sash when no-one is standing in front of the fume cupboard. Continual controlling of the sash opening ensures an optimum working condition with maximum safety. Typically, a passive infrared detector senses the movement of a person in front of the fume cupboard. When the person moves away, out of range of the detector and following a pre-set time delay, the automatic sash closing function is initiated.

(c) Manual volume control damper

The manual damper maintains a constant pre-set air volume even under varying pressure conditions. Such regulation is found in permanent vented units with constant air volume (cabinets, vented underbench units). The required volume of air for these installations is a burden which has been taken into consideration in balancing the room air.

Temporarily vented units, canopies or local extraction hoods etc. which are either switched on and operated at the full pre-set air volume or off, incorporate a damper which sends a signal to indicate its operational condition enabling this to be taken into account in the process of adjusting the air volume levels.

(d) Group controller

The controller constantly receives on-line data on the current individual air requirements from all variable extracting units in the laboratory (fume cupboards, temporary running extracting units). It processes this data and sends a control signal in the form of a nominal electrical signal to the supply air damper which adjusts the volume of air. In this way the group controller acts as a link between the extract air dampers of the individual units and the supply air damper of the laboratory.

Where available, the BMS may undertake the function of the group controller.

(e) Supply air dampers

The damper receives the control signal from the group controller and adjusts the supply for compliance with the applicable specifications for air volume and room pressure.

(f) Supply air grilles

Sufficient air grilles should be allowed for supply air to the laboratory without draughts.

(g) Supply air and extract air ducting

These ensure optimal guiding of air in the room.

9.8.2 Air handling efficiency

Within the modern laboratory the emphasis on safety has led to an increase in the number of fume cupboards, local extract hoods and ventilated cabinets. The resultant demand on air flow creates unrealistically high air change rates. The consequences of not addressing the problem could lead to:

- large air handling equipment;
- large ductwork;
- high energy costs;
- complex control systems.

The first three are a product of the air volumes; safety requirements do not permit air recirculation, therefore, all treated air supplied to the laboratory is dumped. Complex controls are necessary to manage the diversity on air volume demand. Depending upon the number of extract units and the operational requirements, systems may incorporate multiple fan and damper arrangements for both supply and extract air, monitored by probes and sensors. There are a number of methods which may be adopted to improve the efficiency of laboratory air flow.

Fume cupboard face velocity control system and laboratory air input controls

Significant savings can be achieved in running costs to heated or cooled air input to the laboratory.

A number of fume cupboards may be served by a single extraction fan. Make up air supply is introduced to the laboratory via a standard Air Handling Unit (AHU) with heating/cooling coils.

The important feature of this type of system is that the extract fan runs at full volume at all times. This ensures that the discharge velocity remains constant and thus the contaminated air is dumped. As the fume cupboard sashes are closed, the total volume extracted through the fume cupboards is reduced to only 15%. Hence, a fresh air bleed damper is built into the system which allows air to be taken from outside the building through the extract fan to make up the 85% reduction and, thus, maintain the discharge velocity. The fresh air bleed damper can be operated by an adjustable weighted arm, or by an actuator controlled by the extract duct pressure.

The air input system is required to provide make up air for the fume cupboards. The air is taken from outside the building and heated or cooled as required. For laboratories where the building fabric is not well sealed, in order to control the air input, a duct probe is used to produce a signal proportional to the extract volume.

For laboratories where the building fabric is well sealed, it is possible to measure the differential pressure between the laboratory and an adjacent area with a stable pressure regime. This measurement can be used to produce an output signal to control the air input to balance the variable extract volume.

A significant feature of this system is the possibility of applying a diversity factor to the air input and extract units. Typically installations may operate where the air input unit and the extract fan are sized to 50% of the maximum design volume of the total fume cupboards.

This means that 50% of the fume cupboards can be open with the other 50% closed or all the fume cupboards can be half open, i.e., any combination of sash openings up to a total for all fume cupboards of 50% opening. Controls and alarms operate by measuring the face velocity on the fume cupboards. An alarm would be activated centrally and/or on individual fume cupboards if the total 50% opening is exceeded. Application of a diversity factor with an integrated control and alarm system can result in very substantial cost savings.

Secutromb auxiliary air fume cupboards

Conventional fume cupboards achieve their containment by extracting large volumes of heated laboratory air to provide a sufficiently high face velocity to contain fumes. This process can result in a high rate of room air change and heating or conditioning of this air is often expensive. Furthermore, should additional fume cupboards be required, it may not be possible to supply sufficient air necessary for efficient extraction to these cupboards.

The Secutromb fume cupboard works on a completely new and novel principle which involves auxiliary air from outside the laboratory area being supplied to the cupboard. As a result of the configuration of the cupboard's air input plenum ducts and the positioning of the extract take-off ducts, two contra rotating vortices are formed. As the air in the centre of the vortex is moving faster than the air on the outside, a negative pressure is formed in the centre of the vortex and any fumes generated within the fume cupboard migrate to and into the vortex and are then extracted via the extract take-off ducts.

In practice, this means that there is a vertical extract column at each side of the cupboard over its whole height. This ensures good scavenging of the cupboard and, very importantly, the concentration of fumes within the cupboard is very much lower than that found in conventional cupboards. Up to 70% of the total extract volume can be supplied as auxiliary air with only 30% needing to be extracted from the laboratory itself.

The auxiliary air must be heated and be within 8°C of the laboratory air. In air-conditioned laboratories, no cooling is necessary. Auxiliary air should, however, be filtered to ensure plenum gauzes do not become blocked as a result of atmospheric contamination.

As an additional safety feature, an airflow controller may be incorporated. This microprocessor-controlled system monitors the rate of flow of supply/auxiliary and extract air and controls their flow rates within pre-set limits. Airflow controllers have audible and visual alarms to warn in the event of either auxiliary air or extract system failure.

9.9 Safety and containment

Filters

Fume cupboards used for radio-isotope applications normally require the extract system to be fitted with HEPA filters and, in some instances (for example, isotopes of iodine), carbon filters may also be required.

With minor modification and the addition of a pneumatically operated volume control damper, the unit can be used as a constant face velocity module (i.e. total extract volume is variable dependent on sash position).

Maximum permitted leak concentration of test gas in accordance with DIN 12 924

Front sash closed	0.2 ppm
One-third open	0.5 ppm
Fully open	0.8 ppm

Sash lock/airflow failure alarm module

A combined sash lock/airflow failure alarm module should be designed to satisfy statutory safety standards. Generally the unit would comprise three separate parts:

- alarm airflow sensor;
- Printed Circuit Board (PCB) assembly in an enclosure;
- annuciator front fascia plate.

The alarm airflow sensor is typically a hot wire anemometer device. A sensor uses two signal diodes, one of which is heated. The diode is cooled by ambient air passing over it, its signal then being compared with the second unheated diode, which acts as a comparator for variations in ambient air temperature. Velocity sensors are usually installed in the top panel of the fume cupboard and produce a stable signal, which represents the face velocity.

Volt-free contacts may be included for remote monitoring and fume cupboard status and for fan stop-start relay.

Typically the annuciator face-plate incorporates an analogue meter showing 'Safe-Unsafe' face velocity with green and flashing red indicator lights. It may also feature an audible alarm with a mute button to show low face velocity. The face-plate can incorporate fan 'stop-start' buttons. A sash 'high' release button with red and green indicator lights is used where the sash is raised above its working height for setting up experimental apparatus in the cupboard.