1

BUILDING CONSIDERATIONS

1.1 GUIDING CONCEPTS

This chapter deals principally with alternative building layouts for the design and construction of new laboratory buildings. The advantages and disadvantages of a variety of alternative building design strategies are presented, as are preferred design choices. Laboratory requirements based on the various preferred building layout strategies are discussed. During the useful life of a building, laboratories may be renovated several times. Therefore, as much flexibility as possible has been provided so that the health and safety concepts given here may be applied to the renovation of existing buildings as well as to original construction. Facilities undergoing simple upgrading need not be substantially revised to meet the requirements given in this chapter if no safety hazards are present, but close consideration of the precepts detailed in this chapter is warranted when substantial modifications are to be made. Because laboratories may be constructed within building layouts that are less than ideal for the purpose, careful review and application of health and safety requirements will be required. Nevertheless, most safety and health requirements can be applied to many different laboratory and building layouts: It should always be possible to meet essential safety requirements.

1.2 BUILDING LAYOUT

1.2.1 The Building Program

The architect, project engineer, and laboratory consultant, with the assistance of the owner's administrators and laboratory users, develop the building program from analysis of data collected on (1) the number and types of personnel who will occupy the building; (2) the research, teaching, production, or industrial functions to be housed; and (3) the interrelationships of functions and personnel.

1.2.1.1 Program Goals. A building program of requirements is a written document that describes and quantifies the design goals for a building. The goal of a good program is to define a building that will have ample space for the number of occupants and functions it will house, that will function safely, and will realistically meet the owner's needs and budget. A program project team of programmers and design architects and engineers, users, administrators, facilities management, and health and safety professionals from within the organization prepare a building program. The program describes where and for whom the building will be constructed and what building functions and performance levels that

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owners and users require to meet their goals. Architects and engineers use building programs to learn for whom they are designing the facility, what spaces and facilities are required, where functions should be located in relation to each other, and the performance level that will meet the owners' needs. The programming process described in detail below is a consensus-based process. Consensus-based processes actively engage all stakeholders in developing the program of requirements for the program project team to gain as much balanced and comprehensive information as possible. There are other methods that engage only top administrators and scientists, and not stakeholders or health and safety professionals. Using this approach, the owner expedites the program process. It may also be warranted when the project is a start-up research or scientific product development organization, a new government agency, or a new academic department and it is too early for other stakeholders or health and safety professionals to be involved. Basically, the program project team accomplishes the same tasks, but when fewer individuals provide data and opinions, with no input from health and safety authorities and facilities management professionals to interpret data and inform the team of the organization's policies and standard operating procedures, the document may be more generic as a result of the depth of experience of the program project team in place. This is a risk the owner takes.

1.2.1.2 Types of Program Documents. There are three primary types of building programs, categorized based on the owner's project team objectives.

1. A conceptual program, used to test feasibility of a building or renovation project, can also be used for fund-raising and for convincing potential funding sources of the merit and utility of the project. A conceptual program quantifies net usable area or gross area for each department or generic space type. Generic space categories are laboratory, laboratory support, and specialized areas that include office and administration, personnel support, and building support.
2. An outline program lists the specific room types and the number and areas of each, and can be used as a tool for recruiting additional research scientists and for fund-raising.
3. A detailed functional program, the most common program document, is used to estimate construction cost and to build consensus within the proposed group of laboratory occupants and stakeholders. A detailed functional program describes architectural, mechanical, electrical, plumbing, information technology, and fire protection performance criteria for all building functions that must be accommodated. A detailed functional program identifies areas of special concern for safety, such as high-hazard areas that use flammable, toxic, and pathogenic materials or processes; the program also includes the waste removal implications of and facilities for these sensitive materials. The detailed functional program does not need to be written with any preconceived formal design philosophy in mind, except as may be required to incorporate health and safety guidelines. A detailed functional program is intended to enable owners and users to evaluate the building plan, and the engineering and architectural design that the consultant design team ultimately develops.

1.2.1.2.1 Completing the Program Documents. Table 1-1 lists the tasks required for completing the three types of programs. The remainder of this section details the steps and the preferred sequence necessary for the successful completion of the program documents.

STEP 1: EXISTING FACILITY OCCUPANCY ANALYSIS. Beginning the program process with the program team understanding of how the owner uses existing laboratory building(s) that will be replaced by the proposed new or renovated laboratory facility is very important to the outcome of the program document. Existing facility analyses gather and document observations and hard data on occupancy patterns from where the occupants currently work. Factors investigated may include population density, major equipment housed in laboratories, processes conducted in laboratories that impact the size of labs, linear feet (meters) of lab bench, chemical fume hood quantities and distribution, and management of hazardous materials and waste, for example. If future occupants come to the new or renovated laboratory from a number of different buildings or existing laboratories, a sampling of a few laboratories from each relevant department or organizational unit will suffice to enlighten the program team on the manner in which the users organize their space and the efficiencies the owner is able to achieve, or not. It is important to use the owners' facility or space assignment database(s) to analyze occupancy factors such as population density (net area per laboratory full-time equivalent [FTE] positions), average net area of assigned laboratories, proportion of net area for assigned labs to support and shared labs, proportion of net area for nonlaboratory use in the existing building(s), and net to gross area ratio of the existing building.

TABLE 1-1. Program Tasks and Sequence for Types of Program Documents

Step	Task	Conceptual	Outline	Detailed Functional
1	Perform an existing facility occupancy analysis or comparison to a similar facility	Yes	Yes	Yes
2	Perform any special studies or analyses required to help define the project scope	No	Optional	Yes
3	Conduct interviews and meetings with all stakeholders	Yes	Yes	Yes
4	Estabilish new or revised area standards	Yes	Yes	Yes
5	Develop a room type list	No[a]	Yes	Yes
6	Develop room performance specifications	No	No	Yes
7	Diagram typical lab module and all major room types	No	No	Yes
8	Estimate the quantities and net areas for each room type	Yes[a]	Yes	Yes
9	Calculate building net and gross area	Yes	Yes	Yes
10	Diagram spatial relationships of functions	No	Yes	Yes
11	Describe building basis of design for architectural, utlities, electrical, IT, mechanical, plumbing, and FP systems	No	Optional	Yes
12	Model or estimate cost of construction	Yes	Yes	Yes

[a]Conceptual programs have only generic room types: laboratory, lab support, administration, personnel support, and building support. There is no detail.

A second purpose for completing an existing-facility occupancy analysis is to objectively inform the owner and users of their current occupancy pattern, using numerical data and actual photographic documentation of the current status of the existing building, not just the programming team's subjective opinions. This process is like holding a clear, undistorted mirror for both owner representatives and users to look at themselves and how they currently use laboratory buildings. It informs them in new ways of what their goals and expectations could be for the new or renovated laboratory or building. It reduces the number and impact of preconceived notions and political ploys that inevitably arise within group interactions.

If the owner has no existing laboratory facility in which to perform the analysis, the program team with the owner's participation, should select another facility of similar use at a similar organization to analyze. The other facility should be occupied for a minimum of 2 years; otherwise, the analysis may be unrealistic and not helpful. This facility functions as a stand-in for the owner's "in process" laboratory building.

STEP 2: SPECIAL ANALYSES AND STUDIES. Programming of some laboratory facilities requires additional expert knowledge to be brought to the owner and program project team. These special areas of analysis for some research and development laboratory buildings include threat and security, site selection, and environmental impact. Specifically for laboratory buildings undergoing renovation, an analysis of existing facility conditions is very important to complete prior to or during the period of the program process. The following paragraphs will offer perspective on applications of these special analyses and studies on programming laboratory buildings.

Threat and Security Analysis. Because most research, development, testing, and educational laboratories use chemicals and some laboratories also use hazardous pathogenic materials, security and safety of laboratory facilities and occupants are of concern to many laboratory owners, occupants, and users. The National Institute of Building Sciences (NIBS) recommends "Designing buildings for security and safety requires a proactive approach that anticipates [in the programming process] and then protects the building occupants, resources, structure, and continuity of operations from multiple hazards. The first step in the process is to understand the various threats and the risks they pose. . . . This effort identifies the resources or 'assets' to be protected, highlights the possible 'perils' [major natural disasters for example] or 'threats' [terrorism, vandalism, arson for example] and establishes a likely consequence of occurrence or 'risk'" (NIBS, 2010, p. 1).

Building owners who represent corporate, government, and academic organizations need to engage a qualified consultant, an expert in laboratory facilities, to provide "recommendations from a comprehensive threat assessment/ vulnerability assessment/ risk-based security analysis" (NIBS, 2010, p. 1). This limits the potential liabilities of the owner and provides practical design guidelines for the program project team to integrate into the scope of the laboratory building program of requirements. Laboratory buildings for many government agencies require this analysis. The best time to provide for security guidance for a project is before or during the programming process.

Site Selection Analysis. Laboratory owners may not have identified land or a site for the proposed building(s) during the programming phase of the project. Owners may not know which existing building or portion of a building would be the best to renovate by the time a program process commences. This does not pose an insurmountable difficulty for the program project team to successfully complete a program. However, many site issues have a direct impact on estimates of the net-to-gross area ratio and on construction and project costs to owners—Step 12 in the program process. Some decisions owners normally make during the programming process may have to be deferred until the owner selects a site. Owners may elect to conduct a two-stage programming process starting with a conceptual program followed by either an outline or detailed functional program documents performed when the site is selected.

Several site selection issues critical to the health, safety, and environmental aspects of laboratory buildings include the following:

- Availability of and capacity of major utilities at the site
- Safety and security of the facility
- Vehicular and service access to and within the site
- Pedestrian circulation to and on the site
- Subsurface conditions that impact building structure and site drainage
- Surrounding buildings and/or landscape features that impact supply air quality to and dispersion of exhaust effluent from the laboratory building
- Contamination of the soil or water on the site by previous use of the site

Environmental Assessment. If a site is selected or a building identified for renovation, the jurisdiction having authority over that site may require the owner to provide an Environmental Impact Statement (EIS). An environmental assessment (EA) is the process required to produce an EIS. Federal and many state or local government agencies also require an EA to be performed and EIS submitted as part of the official project approval process.

An EA, as defined by the International Association for Impact Assessment (IAIA) is "the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (IAIA, 2012, p. 2). The project program phase is the preferred time to start Step 1, Preliminary Assessment for development of the EA because information is being gathered and initial assumptions are being made that will impact the environment of the site. The second step of the EA, Detailed Assessment, is developed during the project planning phase, and upon completion will be issued in the EIS.

Several components of environmental assessments that influence the development of the building program of requirements include the following adapted from the National Environmental Policy Act, 1978 (40 CFR Part 1500, NEPA Regulations, Section 1508.9):

- Description of the proposed building, construction activity, and an analysis of the need
- Analysis of the site selection procedure and alternate sites
- Baseline [site] conditions and major concerns
- Description of potential positive and negative environmental, social, economic and cultural impacts including cumulative, regional, temporal and spatial considerations
- Identification of human health issues

Facility Conditions Analysis (for Renovations and Additions to Existing Lab Buildings). An existing facility conditions analysis (FCA) should be conducted on laboratory buildings proposed for renovation, whether it is a few laboratories, a floor of the building, or the entire building. Projects where existing buildings will be expanded with laboratory additions also benefit from FCA. FCA offer owners objective, thorough technical knowledge of all major systems of a building with regard to changes in function since the building was constructed, compliance to current building codes, and replacement of equipment and materials based on specific life-cycle data and existing conditions. FCAs are part of successful facilities management practice in operating technically complex laboratory buildings. Especially in times of economic stress or where deferred maintenance is routinely practiced by an organization, an FCA provides the only comprehensive, objective information on building deficiencies. This analysis will guide the owner and design team in making decisions on the scope of the renovation and setting priorities in a rational, well-informed manner, rather than solely by political pressure. It is advisable that the owner makes the full document available for the program project team's review.

STEP 3: INTERVIEWS AND STAKEHOLDER MEETINGS. The program project team of consultants and in-house members of the organization conduct interviews with

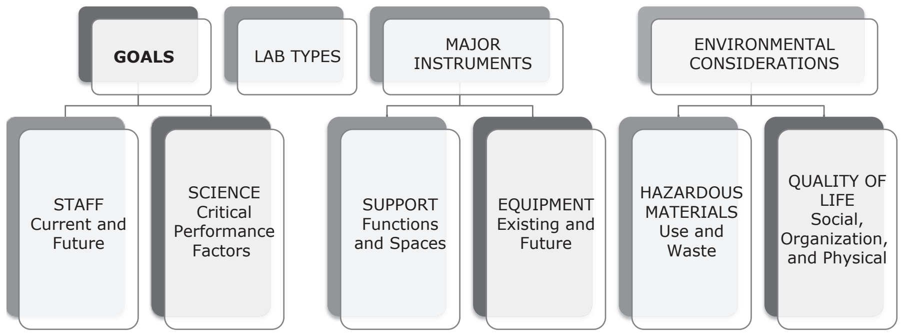

FIGURE 1-1. Sample principal investigator interview agenda.

department heads, principal investigators (PIs), administrative leaders, and laboratory managers for information on current population numbers and functions, and their projections for future capacities. (See Figure 1-1 for a sample agenda for meetings with PIs.) In addition, meetings are held with critical operations and support staff including key laboratory technicians (on PI research teams), facilities management representatives, environmental health and safety professionals, chemical hygiene officers, chemical and supply stockroom staff, materials' handling personnel, housekeeping staff, and any other individuals and operations managers who are involved in operating the proposed building, even if they will not be occupants. In educational institutions, student representatives may participate in meetings or surveys to share their perspectives on building requirements with the program project team. This inclusive approach brings out critical health, safety, environmental, and operations information, as well as hidden assumptions that might otherwise not be revealed to the program project team.

An effective method to manage large and diverse groups of stakeholders is to conduct discussions in well-structured "*Problem Seeking*" (Pena, 2001) workshops. The primary outcome of Problem Seeking is that stakeholders from top to bottom of the organizational hierarchy are placed, at least temporarily, on equal footing to express their observations and opinions about the existing conditions, and more importantly, about the proposed new or renovated facility. Stakeholders hear and see what others in the organization think and share. Comments are recorded graphically, but are unattributed to individuals. Comments then are posted physically and distributed electronically for all stakeholders to review and discuss further. Problem-Seeking workshops are most effective when conducted near the beginning of the programming phase.

When the persons who will be responsible for managing the laboratories, PIs, and occupants are not yet known, the program project team consults with the administrative leaders of the organization who are to hire these primary staff members. The leaders establish what functions will be carried out in the building and define the owner's goals. When no better information is available to the program project team, allocations of the major divisions of space can be estimated based on the occupancy patterns of well-functioning buildings of similar purpose. Information from such indirect sources may (1) be nonspecific to the actual project, and (2) produce less precise estimates of needs than information that otherwise would be obtained directly from future occupants, building operators, and administrators.

To estimate a laboratory building population for a conceptual program when specific numbers of FTEs are unobtainable, the programmer can construct a model to estimate population based on an understanding of the most commonly observed laboratory working groups as given in Table 1-2. These figures refer to FTE positions, not head count. FTE positions are often a lower number than head counts. FTE calculation aggregates part-time workers to the 40-hour, or other, workweek equivalent of a full-time worker. For example, two part-time technicians equal one FTE. According to the total amount of time four to six undergraduate students work with a research team, they may equal 1 FTE. This can become a major adjustment for actual laboratory and building population figures.

The example used here is based on a typical research laboratory at a medium-sized higher-education academic institution: Staffing for different laboratory types and for other sizes of research organizations will differ. In the research and development industry, there are wide variations based on the science discipline pursued and the type of organization: academic, corporate, or government. Using the team sizes given in Table 1-2, administrative and scientific leaders can estimate the optimal population of scientists in the facility that they feel will meet the operational research and development objectives for the organization. They may propose several variations to investigate the implications for the

TABLE 1-2. Conceptual Program: Research Team FTE Population Estimates

Team Members	Very Small Team FTE	Small Team FTE	Medium Team FTE	Large Team FTE	Very Large Team FTE
Principal Investigator	1.00	1.00	1.00	1.00	1.00
Research Assistant		1.00	1.00	2.00	2.00
Postdoctoral Student		1.00	2.00	2.00	4.00
Technician			1.00	2.00	4.00
Graduate Student	1.00	1.00	1.00	3.00	6.00
Undergrad Student[a]			0.50	1.00	2.00
Clerical Assistant	0.25	0.25	0.50	1.00	1.00
Total Team Population	2.25	4.25	7.00	12.00	20.00

[a]Undergraduate (UG) students are part time in laboratories. FTE = full-time equivalent. 4 UG = 1 FTE

net area required just to accommodate the scientists. Area allotments for extra-large groups of over 20 persons that are encountered in some laboratory settings can be roughly extrapolated from the values given in Tables 1-2 through 1-5.

It is our experience that even when a new facility is well planned and well constructed, demand on it can go far beyond conservative estimates that were established during the programming phase. Within a few years, occupancy of a successful new laboratory can reach 120–150% of the original population envisioned in the building program. Therefore, organizational leaders should carefully consider the total FTE population with input from the program project team.

Step 4: new or revised net area standards. The next step is to establish research net assignable area standards or to revise current standards, if they exist. The definition of *net area* as established by the Building Owners Management Association (BOMA) is "the total floor area within the walls of a space. Measure length and width from centerline-to centerline of walls (except the exterior walls)" (BOMA Z65.1, 1996). "Net assignable area does not include area used for public corridors, structural elements, exterior walls, mechanical equipment rooms, or duct and pipe shafts, toilets, and other building support facilities. Those elements are accounted for in building *gross area*" (BOMA Z65.3, 2009). Area standards are calculated from the existing laboratory population density by making an analysis of current and more desirable laboratory occupancy patterns, assessing the adequacy of existing conditions and net assignable areas, and then setting realistic but safe area goals for the new facility. Laboratory parameters useful to establish standards per FTE are bench length, shared equipment wall length, computational station length, length of chemical fume hood(s), hazardous waste storage area, and linear feet of sink.

For example, in Table 1-3, these parameters are applied to a typical biochemistry and an organic chemistry research laboratory, respectively. As illustrated in the table, data from existing conditions can be used for developing new standards. For some parameters, the recommended new standards are adjusted up or down from current existing laboratory averages in linear measure then converted to net area.

For conceptual programs, an alternative method based on commonly observed laboratory settings must be resorted to when there is no existing facility to analyze. The example of area standards calculated per FTE research occupant shown in Table 1-4 is derived from a database of areas for several functions typical for a range of general chemistry and biomedical research laboratories in higher-education academic facilities. Because research in academic institutions relies on availability of cheap student labor, area allotments or standards per FTE occupant for academic research laboratories are factors of 2 to 3 lower than for corporate, industry, and some government agency facilities. The estimated total net area divided by the total FTE research population establishes the area per FTE researcher figures shown in Table 1-5.

Definitions of the major functional categories listed in Tables 1-4 and 1-5 follow.

Laboratory is a category of net assignable area in which diverse mechanical services and special supply and exhaust ventilation devices are available. Laboratories are often modular, that is, designed on a standardized size or a precise multiple or simple fraction of that standard size. See Step 7 and Chapter 2, Section 2.2.1 for a discussion of the laboratory module.

Laboratory support area is a category of net assignable area that contains the same services and ventilation facilities as the laboratory area, but may or may not conform to the same modular laboratory size or configuration. Dedicated laboratory support areas are assigned to individual PIs, and may adjoin the modular laboratory

TABLE 1-3. Examples of Current and Recommended New Standards for Biochemistry and Organic Chemistry Laboratory Facilities[a]

Workstation	Biochemistry Research								Organic Chemistry Research							
	Existing Lab Averages				Recommended New Standards				Existing Lab Averages				Recommended New Standards			
Component Measure	lft	m	NASF	NASM	lft	m	NASF	NASM	lft	m	NASF	NASM	lft	m	NASF	NASM
Bench	5	1.52	27.5	2.55	7	2.13	38.5	1.76	8	2.44	44.0	1.21	6	1.83	33.0	3.07
Equipment Wall	2	0.61	11.0	1.02	4	1.22	22.0	1.00	2	0.61	11.0	0.48	4	1.22	22.0	2.04
Chemical Hood	1	0.30	5.5	0.51	2	0.61	11.0	0.50	5	1.52	27.5	0.24	8	2.44	44.0	4.09
Lab Sink	1	0.30	5.5	0.51	1	0.30	5.5	0.25	1	0.30	5.5	0.24	1	0.30	5.5	0.51
Waste Material Handling & Stg	0	0.00	0.0	0.00	1	0.30	5.5	0.25	0	0.00	0.0	0.00	2	0.61	11.0	1.02
Write-up Bench	3	0.91	16.5	1.53	4	1.22	22.0	1.00	3	0.91	16.5	0.72	4	1.22	22.0	2.04
Dedicated Support	4	1.22	20.0	1.86	7	2.13	40.0	3.72	4	1.22	20.0	1.86	4	1.22	20.0	1.86
Shared Support	6	1.83	30.0	2.79	7	2.13	40.0	3.72	4	1.83	20.0	2.79	8	2.44	40.0	3.72
Common Support	2	0.61	10.0	0.93	2	0.61	10.0	0.93	2	0.61	10.0	0.93	2	0.61	10.0	0.93
Assigned Desk[b]	0	0.00	0.0	0.00	5	1.52	30.0	2.79	0	0.00	0.0	0.00	6	1.83	30.0	2.79
BIOCHEM TOTALS	**24**	**7.31**	**126**	**11.70**	**40**	**12.19**	**224.5**	**15.92**	**29**	**9.45**	**155**	**8.47**	**45**	**13.71**	**237.5**	**22.07**

[a]All net areas include half module sf per linear foot, or 5.5 sf per 1 lft (1.67 sm per 1 m length), includes the width of the work zone and lab aisle in front.
[b]Office area for staff and students is recommended to be located outside and separate from laboratories.

units or may be elsewhere. Shared laboratory support is assigned to and used by more than one PI or department. Laboratory support services assigned to a specific department may function as specialized common resources by researchers throughout a building.

Administration area is a category of net assignable area that contains only standard commercial electrical, telecommunication, and office ventilation services. Ventilation air from these areas may be recirculated. If the new laboratory building is one of a number of similar buildings on a well-established campus or industrial complex, administrative and most clerical personnel may be located in an entirely separate building. When administrative personnel are located within a building that is principally devoted to laboratories, their room types must be listed and the areas estimated in the program tabulation.

Personnel support area is a category of net usable area that is similar in function to an administration area, but may contain added mechanical and HVAC services to provide for special functions, such as toilets, shower and locker rooms, cafeterias and kitchens, etc. Personnel support requirements can be estimated in the same way as administrative functions. However, building codes regulate capacities requirements for restrooms and other personnel support functions. When certain needed facilities exist nearby (e.g., a cafeteria), they may not need to be duplicated in the new or renovated laboratory building.

Building support area is a category of net usable area or gross area that may contain special mechanical and HVAC facilities to provide for special needs. Every laboratory building requires adequate areas for materials handling, maintenance, housekeeping, and special storage. These room categories also should be listed in the program tabulation. When a loading dock and temporary storage room(s) for daily deliveries and shipments are not conveniently close, alternative facilities must be provided for these activities in the building. Dedicated storage rooms for maintenance equipment and supplies are as important as storage space for scientific apparatus and materials. Table 1-4 shows a minimum estimated area of 10 net area square feet (NASF) (0.93 net area square meters [NASM]) per FTE researcher for building support. The program project team should consider carefully investigating and revising this estimate as the program process proceeds and as more detailed information emerges.

Animal facility area requirements may be the most difficult research function to estimate. The net area planned for animal facilities per FTE researcher may vary from 0 to 150 NASF (13.94 NASM) and greater. Very careful consideration must be given to the anticipated research animal demands to develop facilities of appropriate size within new or renovated laboratory buildings. See Chapter 22, Animal Research Laboratory, for more information.

Area standards are used to estimate the net assignable area of research and other building functions for each research team size, as shown in Table 1-5.

As shown in Table 1-6, different activities and scientific disciplines have different area requirements per

TABLE 1-4. Minimum Net Area Standards for Typical Academic Research Laboratories

Laboratory Area Category	Very Small Team		Small Team		Medium Team		Large Team		Very Large Team	
	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE
Total FTE Population	**2.25**		**4.25**		**7.00**		**12.00**		**20.00**	
PI Office	54	4.65	29	2.79	18	1.86	12	1.39	12	0.93
Clerical Office	20	1.86	20	1.86	10	0.93	5	0.46	5	0.46
Staff/ Student Offices[a]	30	2.79	30	2.79	30	2.79	30	2.79	30	2.79
Modular Laboratory	130	12.08	130	12.08	130	12.08	120	11.15	120	11.15
Dedicated Lab Support	40	3.72	40	3.72	40	3.72	30	2.79	20	2.79
Shared Lab Support	40	3.72	40	3.72	40	3.72	30	2.79	20	2.79
Common Lab Support	20	1.86	20	1.86	10	0.93	10	0.93	5	0.46
Animal Housing Facility[b]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Subtotal NASF per FTE	334	30.68	309	28.82	278	26.03	237	22.3	212	21.37
Administration Offices[c]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Personnel Support[d]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Building Support	10	0.93	10	0.93	10	0.93	10	0.93	10	0.93
Total Net Area/FTE Laboratory Occupant	**344**	**31.61**	**319**	**29.75**	**288**	**26.96**	**247**	**23.23**	**222**	**22.30**
	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE

[a]Office area for staff and students is recommended to be located outside and separate from laboratories.
[b]Estimates of animal housing must be calculated on factors other than count of laboratory full-time equivalents (FTEs). See Chapter 22, Animal Research Laboratory.
[c]Estimates of administrative offices and support depend on organizational factors not count of laboratory FTEs. Prepare a separate program accounting of administrative requirements.
[d]Estimates of personnel support depend on building code and factors other than count of laboratory FTEs. Prepare a separate program accounting of personnel support requirements.

TABLE 1-5. Estimated Net Areas for Typical Academic Research Laboratories

Laboratory Area Category	Very Small Team		Small Team		Medium Team		Large Team		Very Large Team	
	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM
Total FTE Population	2.25		4.25		7.00		12.00		20.00	
PI Office[a]	122	10.46	123	11.86	126	13.02	144	16.68	240	18.60
Clerical Office (shared)	45	4.19	85	7.91	70	6.51	84	7.73	120	11.04
Staff/ Student Offices[b]	68	6.28	128	11.86	210	19.53	360	33.48	600	55.80
Modular Laboratory	293	27.18	553	51.34	910	84.56	1,440	133.80	2,400	223.00
Dedicated Lab Support	90	8.37	170	15.81	280	26.04	360	33.48	400	55.80
Shared Lab Support	90	8.37	170	15.81	280	26.04	360	33.48	400	55.80
Common Lab Support	45	4.19	85	7.91	70	6.51	120	11.16	100	9.20
Animal Housing Facility[c]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Subtotal NASF per FTE	752	69.03	1,313	122.49	1,946	182.21	2,868	269.81	4,260	429.24
Administration Offices[d]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Personnel Support[e]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Building Support	23	2.09	43	3.95	70	6.51	120	11.16	200	18.60
Total Net Area	**774**	**71.12**	**1,356**	**126.44**	**2,016**	**188.72**	**2,988**	**280.97**	**4,460**	**447.84**
	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM

[a]Office area for principal investigator (PI) of large and very large teams includes area for team meetings within or adjacent to PI office.
[b]Office area for staff and students is recommended to be located outside and separate from laboratories.
[c]Estimates of animal housing must be calculated on factors other than count of laboratory full-time equivalent positions (FTEs). See Chapter 22, Animal Research Laboratory.
[d]Estimates of administrative offices and support depend on organizational factors not count of laboratory FTEs. Prepare a separate program accounting of administrative requirements.
[e]Estimates of personnel support depend on building code and factors other than count of laboratory FTEs. Prepare a separate program accounting of personnel support requirements.

TABLE 1-6. Sample Research Net Area Standards per FTE Occupant for a Variety of Science Disciplines

Primary Activity	Office Use				Laboratory				Lab Support				Total Net Area/FTE[a]			
	SF	SF	SM	SM	SF	SF	SM	SM	SF	SF	SM	SM	SF	SF	SM	SM
	min	ave	min	ave	min	ave	min	ave	min	ave	min	ave	min	ave	min	ave
Analytical Chemistry	57	90	5.3	8.4	110	150	10.2	14.0	20	35	1.9	3.3	187	275	17.4	25.7
Biochemistry	57	90	5.3	8.4	130	175	12.0	16.3	60	80	5.6	7.4	247	345	22.9	32.1
Cell/ Tissue Culture	57	90	5.3	8.4	95	130	8.8	12.0	95	100	8.8	9.3	247	320	22.9	29.7
Molecular Biology	57	90	5.3	8.4	120	130	11.1	12.0	100	120	9.3	11	277	340	25.7	31.5
Organic Chemistry	57	90	5.3	8.4	150	190	14.0	17.7	40	50	3.7	4.6	247	330	23.0	30.7
Physical Chemistry	57	90	5.3	8.4	170	200	15.8	18.6	30	40	2.8	3.7	257	330	23.9	30.7
Physiology	57	90	5.3	8.4	150	170	14.0	15.8	20	40	1.9	3.7	227	300	21.2	27.9

[a]*Note*. Total areas omit allocations for animal facilities, lab shops, administration, personnel or building support. FTE = Full-time equivalent.

FTE. Two primary factors that distinguish net area standards among various experimental science activities and disciplines are the recommended area per researcher for (1) modular laboratory units and (2) laboratory support categories, which may be dedicated, shared, and common support facilities, as defined earlier. There are fewer functional differences in allocation of office space attributable to the scientific discipline than there are differences that are influenced by an organization's culture and adherence to hierarchy. In some organizations, the size and qualities of an office precisely indicate the individual researcher's status to the square foot!

Step 5: room type list. Outline and detailed functional building programs provide lists of all proposed room types with information that relates the nature of the research, equipment, and activities that will take place within each of them. These programs have more specific information than conceptual programs do. However, as in the conceptual program, there are five general area and function categories, not including structural and mechanical spaces: (1) laboratories, (2) laboratory support facilities, (3) administration, (4) personnel support facilities, and (5) building support, as described in Step 4. The National Center for Education Statistics publishes the *Integrated Postsecondary Education Data System* (NCES, 2012), a list of approved room-type names for colleges and universities. Identifying room types by IPEDS numbers as well as by name and program ID is often used in university space databases and is also helpful in making data sorts and for quality control in the compilation of program tabulations.

There are many special laboratory types: general chemistry, physics, controlled environment, animal, teaching, and more. A number of types are discussed in considerable detail in Part II of this book. Various office spaces that are directly involved in research activities, such as those assigned to PIs, research staff, students, and administrative personnel, as well as research team conference rooms are included in laboratory room type list. Other types of offices are included under administrative facilities. Laboratory room types that may be used for teaching must be clearly designated as such because many states have separate building codes governing the construction of teaching facilities.

Laboratory support facilities include the following types: equipment and storage rooms, special instrument rooms, data processing and computer server facilities, glassware washing rooms, sterilization facilities, preparation rooms for media and solutions, sample processing and distribution rooms, machine shops, electronics shops, darkrooms, and a wide variety of imaging suites that may contain microscopes and their associated spectroscopy and computer equipment. Lists of support facility types are extensive.

Administration facilities that do not directly support research program activities include private offices, group offices, and clerical pools. Business offices, personnel record offices, and data processing offices are assigned to administration of the building or to general administration of the organization. Other administrative facilities include libraries; conference rooms; seminar rooms; auditoria; and supply, copy, and mail rooms.

Personnel support facilities include reception areas and lobbies, toilets, changing rooms, locker and shower rooms, health and first-aid offices, lounges, meeting rooms, vending or dining facilities, kitchens, and recreation areas that are indoors. Outdoor recreation areas are not counted in the net assignable area of a building, but need to be documented in the proposed scope for site development.

Building support facilities include shipping and receiving areas, chemical or flammable liquid storerooms, and storerooms for radioactive, chemical, and biological hazardous wastes, maintenance, equipment, housekeeping, shops, supply and stockrooms. Some types of building support rooms are discussed in Part III of this book.

The amount of laboratory area available in a building can be increased at a later time by converting facilities for nonlaboratory functions, such as offices, stockrooms, and personnel support areas. However, to do this safely, efficiently, and cost effectively, advance planning is required to provide reserve capacity in heating, ventilating, and air-conditioning, electrical services, and piped utilities to significantly increase the delivery of building services to new labs. Demand and capacity standards for ventilation, cooling, electricity, water, waste drainage, gas, and so on are far greater for laboratories than for nonlaboratory functions (see Section 1.3). Normal commercial and residential engineering diversity factors for electrical and cooling capacity do not apply to laboratory use. Laboratory equipment may operate constantly (24/7); electrical loads are typically high. This, in turn, puts a greater and more sustained demand on building cooling equipment. Therefore, building program room lists should (1) identify all nonlaboratory rooms and spaces that are likely to be converted to laboratories when the need arises in the future and provide these spaces with reserve capacity, or (2) specify the proportion of nonlaboratory area that should be engineered for future conversion to laboratories.

STEP 6: LABORATORY PERFORMANCE CRITERIA DATA. Detailed functional programs provide comprehensive information on performance criteria for each individual laboratory and generic laboratory (or room) types, based upon what future occupants know or assume at the time of program interviews. This data can be updated at any time during programming and design phases, as more information emerges in later discussions with users. This form provides essential scope and quantity information for the entire project design team, but particularly for building design engineers. Laboratory performance criteria data sheets are a primary communications tool between laboratory design architects and engineers. In addition, owners and users refer to these data sheets throughout design and construction phases, to make sure all their requirements are addressed in the design documents and for quality assurance during construction.

Nonlaboratory room data sheets may be simplified, if desired, because generally there are far fewer technical requirements in office, classroom, and personnel support room types. The data categories often found in laboratory performance criteria data sheets are

- Laboratory (or room) type, special classification, and assignment information
- Occupancy data, such as number of occupants and estimated hours of occupancy
- Lists of requirements for mechanical and piped utility systems and fixture types
- Lists of piped utility requirements and estimates of outlets for each
- Lists of fire protection systems and safety equipment
- Lists of requirements for electrical, stand-by, and emergency power, with estimates of outlets for each service
- Lists of requirements for information technology, telecommunications, and audio visual equipment and systems
- List of probable major equipment
- Categories of chemicals that may be stored, with estimated volumes, if available
- Storage requirements for chemicals and compressed gas cylinders
- Safety equipment requirements
- Number and type of chemical hoods, biological safety cabinets (BSCs), other hoods; any other special exhaust requirements
- Number of workstations and types of benches
- Architectural, material, and finish requirements

Figure 1-2 shows a form that may be used to gather the laboratory performance criteria necessary to facilitate detailed functional program documents. In the detailed functional program document, diagrammatic plans (Step 7) may be attached to data sheets for each laboratory or room.

Chemical Inventory Data. The laboratory performance criteria shows a simple snapshot of several classes of hazardous chemicals and proposed volumes to be used and stored in each laboratory.

This information can raise "red flags" to the laboratory planner and design team on chemical use that may have a significant impact on the design of certain laboratories, e.g., safety ventilation and fire protection systems, as well as fire-resistive construction. However, the chemical inventory data as provided in the presented form is unfortunately insufficient data for the laboratory planners and design team to design the laboratory building. Full and up-to-date chemical inventories are needed from all occupants. Many organizations collect and keep this information current. If an inventory is available, the Chemical Hygiene Officer (CHO) or Environmental Health and Safety Office needs to provide the design team with lists of total volumes by chemical classification: explosives, flammable liquids,

LABORATORY PERFORMANCE CRITERIA DATA SHEET

Program ID No.
Department
Assignment
Space Name

Classification
BSL 1,2
BSL 3, 4
ABSL 2
ABSL 3
cGLP
cGMP
Clean Room Class

Client Name
Project Name
Recorded by Date Final

OCCUPANCY

Hrs. Occupancy	No. Rooms
No. Occupants	Room Area
No. Animals	Species

FUNCTIONAL RELATIONSHIPS
Primary Room Activity
Secondary Activity
Room Adjacencies
Floor Adjacencies

ARCHITECTURAL

Floor Material	Seamless	
Base Material	Height	
Wall Material	Finish	
Ceiling Material	Height	
Door Material	Type	
Door Width	Height	Rating
Door Hardware		
Acoustic Criteria		
Window Treatment		
Vibration Control	Floor Load	
Hoist	Load Rating	

CASEWORK

Standing Bench	LF	Type	Depth
Seated Bench	LF	Type	Depth
Wall Cupboard	LF	Type	Depth
Tall Cupboard	LF	Type	Depth
Mobile Bench	LF	Type	Depth
Lab Table	LF	Type	Depth
Adjustable Shelving	LF	Type	Depth
Reagent Shelving	LF	Type	Depth
Countertop Material			
Other			

LIGHTING

Fixture	Qty	Type
Fixture	Qty	Type
Fixture	Qty	Type
Controls		
Timer		Type

MECHANICAL

			Summer	Winter
Temperature	Set	Range		
Relative Humidity	Set	Range		
Filtered Supply	YES	Type		
Chemical Fume Hood	Qty	Type	Size	
Biological Safety Cabinet	Qty	Type	Size	
Point Exhaust	Qty	Type	Size	
Snorkel Exhaust	Qty	Type	Size	
Canopy Exhaust Hood	Qty	Type	Size	
Other Local Exhaust	Qty	Type	Size	
Filtered Exhaust	Qty	Type		
Other Consideration				

SAFETY EQUIPMENT

Flam Liq Stg Cab	Qty	Type	Size
Corrosive Stg Cab	Qty	Type	Size
Fire Extinguisher	Qty	Type	Size
SCBA	Qty	Type	
Emergency Eyewash	Qty	Type	
Safety Shower	Qty	Type	
Gas Cylinder Rack	Qty	Type	
Other	Qty	Type	

PLUMBING		Wall Bench Hood			Wall Bench Hood
Lab Sink	Qty		Local Polisher	Qty	
Cup Sink	Qty		Process CW	Qty	
Hand Wash Sink	Qty		Comp Air	Qty	
Open Drain	Qty		Vacuum	Qty	
Cold Water	Qty		Nitrogen	Qty	
Hot Water	Qty		Steam	Qty	
Purified Water	Qty		Natural Gas	Qty	
Floor Drain	Qty	Size	Other	Qty	

ELECTRIC POWER		Amps	Volts	Phase	Qty or Spacing	UPS	Emerg	Islolated Circuit
Bench	Qty							
Bench	Qty							
Wall	Qty							
Wall	Qty							
Wall	Qty							
Chemical Hood	Qty							
Biosafety Cab	Qty							

TELECOMMUNICATIONS

Phone	Qty	Wireless
Internal Network Port	Qty	Type
Outside Network Port	Qty	Type

AUDIOVISUAL & SECURITY SYSTEMS

VCR & Screen	Qty	Type
Microphone	Qty	Type
PA or Loudspeaker	Qty	Type
Lab Entry Security	Qty	Type
CCTV	Qty	Type
Other	Qty	Type

CHEMICAL HAZARDS		Liquid	Solid	**GAS CYLINDERS**		Liquid	Gas
Combustible	Qty			Combustible	Qty		
Corrosive	Qty			Corrosive	Qty		
Oxidizer	Qty			Oxidizer	Qty		
Cryogenic	Qty			Cryogenic	Qty		
Flammable	Qty			Flammable	Qty		
Toxic	Qty			Toxic	Qty		
Highly Toxic	Qty			Highly Toxic	Qty		
Radioactive	Qty			Pyrophoric	Qty		
Select Agent	Qty			Other	Qty		

PHYSICAL HAZARDS

Laser	Qty	Type
X-Ray Source	Qty	Type
Accelerators	Qty	Type
Other Radiation	Qty	Type

MAJOR EQUIPMENT - Manufacturer and Model Number

1	Qty
2	Qty
3	Qty
4	Qty
5	Qty
6	Qty
7	Qty
8	Qty
9	Qty
10	Qty
11	Qty
12	Qty
13	Qty
14	Qty
15	Qty

FIGURE 1-2. Laboratory performance criteria data form.

flammable gas, combustible liquids, cryogenic oxidizers, oxidizers, water reactives, unstable reactives, organic peroxides, detonatable organic peroxides, irritants, corrosives, toxic and highly toxic chemicals. The International Building Code (IBC), and the former Uniform Building Code (UBC), and Building Code Officials' Association (BOCA) tables of maximum allowable quantities of hazardous chemicals are all based on these standard chemical classifications. A typical inventory list of 10,000 and more separate chemicals is only helpful to the design team for its standard chemical classifications. See Section 1.2.4.2 for how this data is used in the laboratory planning process.

Equipment Inventory Data. In the case of a program for a building that will be occupied by personnel relocated from another laboratory building, consider developing a comprehensive equipment inventory to supplement partial information provided on the laboratory performance specification data sheets. This type of inventory includes not only the list of existing and proposed equipment with model and manufacturer data, but photographs of existing units and cut sheets of new units, as well as equipment installation specifications that can be obtained from manufacturer's installation manuals. Providing thorough information on scientific equipment in the programming phase, aids mechanical, electrical, and plumbing (MEP) engineers to list and describe the required utilities and systems in the Basis of Design (BOD) program Step 11. During the design phase, equipment inventory data is required for engineers to provide the most accurate cooling load calculations, diversity factor estimates, and utility provisions for equipment in each laboratory.

The equipment inventory and survey are additional services and are usually contracted separately from the program document. Performing equipment inventory during the programming phase is highly recommended.

Step 7: room-type diagrams and net area estimates. At this point in the programming process, the program project team has gathered considerable information on laboratory users' needs and requirements for each proposed laboratory. For outline and detailed functional programs, room lists have been generated. To estimate the net areas of each room type the programmer needs to apply two methods: (1) Generate options on laboratory module dimensions, configurations, and net area; and (2) test area estimates by generating simple line diagrams of all laboratory room types using the module template. Figures 1-3 and 1-4 are examples of single and double modules. Laboratory sizes are determined by multiples of or simple fractions of single modules. Multiple modules are generally arranged in linear arrays.

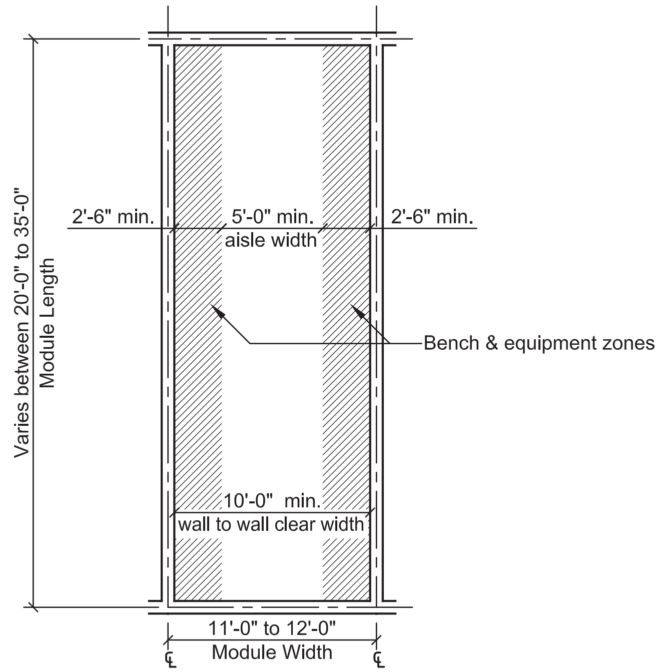

FIGURE 1-3. Plan of single module lab.

See Section 1.2.4 for a detailed description of laboratory module planning considerations. Diagrams of nonlaboratory rooms, such as offices, meeting rooms, etc., provide good tests of area estimates. Below are some basic concepts to be followed.

1. Modules for laboratory space have three dimensions, but for area estimating purposes, only the floor dimensions are needed. Acceptable single module widths for typical "wet" (those having water and using chemicals) laboratories for many scientific and engineering disciplines, vary from a minimum 10 ft 6 in. (3.2 m) to a generous 11 ft 6 in. (3.5 m). Modules are aligned in a row or other basically linear arrays. Module depths may vary from building to building, but within a laboratory building usually one depth is standard. Commonly, module depths vary from a minimum of 20 ft up to 35 ft (6.1–10.67 m). This combination of dimensions offers a range of module areas from a minimum of 220–402 NASF (20.4–37.3 NASM). Determination of the module dimensions has a direct impact on the building structural grid layout. During the design phase, slight adjustments in the module proportions may occur to accommodate structural requirements.

   Net area standards set in Step 4 can be used to test the most suitable module dimensions and area. The number of linear feet of bench and wall for locating freestanding equipment is one key

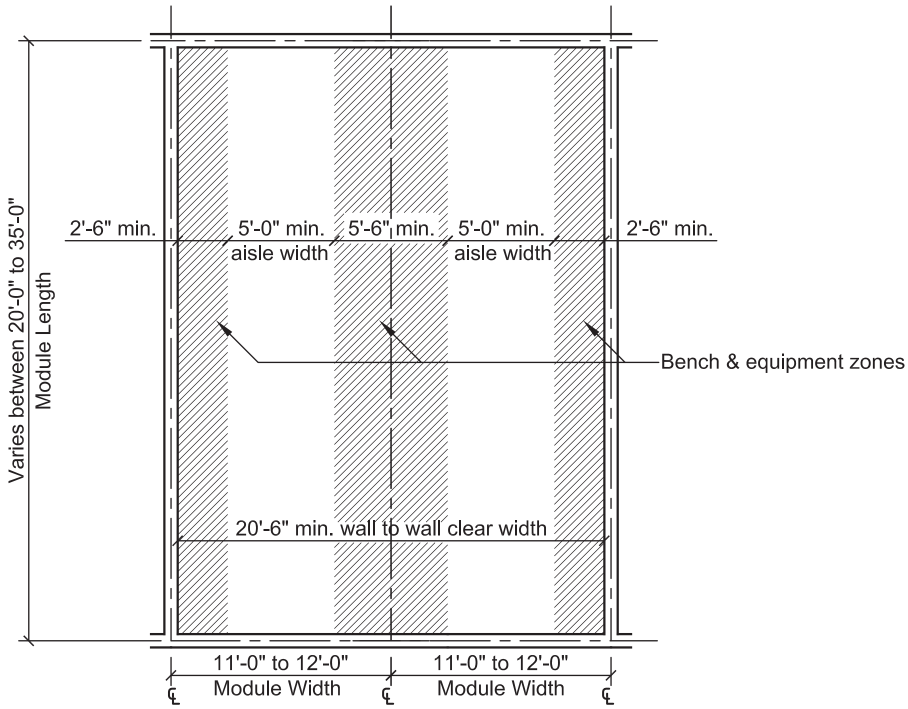

FIGURE 1-4. Plan of two module lab.

factor. For example, if area standards call for 15 linear feet (lft) (4.57 m) of bench, 5 lft (1.52 m) for equipment, and 4 lft (1.21 m) for a computer station at each bench, the programmer may select a module length of 32 lft (9.75 m) total. Thirty-two linear feet allows for the required bench, equipment, and computer station, but also a 5 lft (1.52 m) laboratory aisle and 3 lft (0.91 m) for another function in the area standards. The programmer may select 11 lft for the module width (see Section 1.2.4). These dimensions make a module of 352 NASF (32.7 NASM).

2. With a "draft" module, the programmer will diagram all the laboratory types to test area estimates and to test the size of the module. This is an iterative process to find a single module that provides the best fit for functions listed in the draft program. In another example, the program may call for a cell culture laboratory for one-person occupancy and one BSC with area for stacking incubators, one bench with a lab sink, a microscope table, and one refrigerator. The programmer will diagram these bench and equipment components on the module template. The area required for these functions requires less than a full module, but close to half a module. The programmer will graphically determine what simple fraction of module area is required to design a safe cell culture laboratory. This area will appear in the program area tabulation. Diagrams are a good test of optimal and efficient area, if all the equipment, functional, and safety information is available.

Step 8: Quantities of room types. Three primary factors determine the quantities of room types: driven by headcount, influenced by building geometry, and balanced between shared and proprietary facilities.

The first factor is the count of functions stated by users and recorded in the project notes. For example, if there are 15 PIs in experimental sciences in a department, it is logical and very likely there will be 15 laboratories—minimum and of various sizes—and 15 PI offices. Functions and room types that are based on head count are relatively straightforward to estimate.

The second factor is based on the geometry of the proposed building or renovation, the number of levels, number of wings or other building layout conditions that influence access to shared and common functions. For example, if the proposed building has three occupied floors and PIs require a controlled environment room on the same floor as their laboratories, then it is reasonable that the program will provide at least one controlled environment room per floor, with a total of three or more in the building. Another example is if each laboratory floor is divided by a large atrium surrounded by PI offices, the program may provide two controlled environment labs per floor. There is a safety consideration behind this decision. With one in each wing, scientists and staff, carrying potentially hazardous materials, do not have to cross the atrium and office suite to access a controlled environment room. These issues are relatively clear to determine once the building layout is designed. In the program phase, that information may not be known. The programmer may have to make a judgment call without it or make a note to allow a change in the number of those rooms later, during the design phase. However, the third factor is more complex to consider and requires sometimes difficult and potentially contentious discussions among the scientific personnel and laboratory managers.

Questions concerning the use of centralized versus proprietary facilities assigned to individual investigators or research teams is the third factor that must be answered before it is possible to complete quantification of each type of support room and laboratories that will appear on the room-type list. Outline and detailed functional building program processes address the major issue of which facilities will be repeated on each laboratory floor: those shared by occupants of a department, those common to all occupants of the building, and those provided outside the building.

For example, controlled environment rooms may be provided on each floor of a multilevel laboratory building, but only one radiation laboratory may be provided for all members of a department that requires it. A shipping and receiving dock is an example of a single facility for use by an entire building. An example of a support facility that may be located exterior to a laboratory building in a separate structure is a flammable chemical storage facility. Although it is often more economical to build centralized laboratory support facilities rather than to duplicate them for each department or laboratory group, costs for operating and administering centralized services must be taken into account in owners' operations budgets.

In the programming phase, the program project team resolves all issues of centralized and shared versus proprietary facilities with PIs, users, laboratory managers, and the owner's representatives. After that, the number of each type of room can be estimated. This task should not be deferred until the design phase because changes can have a serious impact on building area after the building construction budget is set. However, some minor adjustments to the specific number and distribution of some support rooms may be made during the design phase without serious consequences.

STEP 9: BUILDING NET AND GROSS AREA CALCULATION. Net assignable area is the unit of measure discussed in Steps 1–8. This area is easy to explain and visualize; programmers often bring bright-colored masking tape to user group meetings and simply put the tape on the floor to demonstrate the measure in full scale. Users can look at it and walk around the perimeter to gain another, kinesthetic understanding of the area numbers. The other measures of area used by architects, engineers, and particularly the construction industry, are more difficult to illustrate directly.

Planners and architects use a number of terms to characterize area data, as shown above in Step 4, for "net assignable area." Terms adopted by the Building Owners and Managers Association (BOMA Z65.1, 1996) are frequently referenced. Here are definitions of a few useful terms.

Net assignable area is the floor area, excluding interior partitions, columns, and building projections, that lies within the walls of a room. It refers to the program total area for rooms and spaces on the room-type list assigned to or available for assignment to a specific occupant, group, or function. Net assignable area may also refer to the total assigned floor area within all rooms and spaces on the room-type list under all categories except for personnel and building support.

Net usable area is floor area that is assigned or available for assignment to a specific occupant, department, or function, and includes area occupied by interior walls, columns, and building projections, but it excludes public circulation areas such as exit corridors, stairs, elevators, and vertical utility shafts. Net usable area may also define the total floor area within the building's exterior wall enclosure that includes floor area taken up by the structure and partitions, but excludes public circulation areas and vertical shafts.

Departmental gross area is the floor area within the exterior wall enclosure assigned to a specific group or department. It includes secondary, private circulation hallways within the department's boundaries, interior walls, columns, and building projections. Departmental gross area is usually synonymous with rentable area.

Gross area is the total building area (BOMA Z65.3, 2009). This is the only measure that the construction industry uses for building cost estimating and benchmarking. Gross area includes the area occupied by the structure, exterior walls, partitions, and vertical shafts plus all usable public areas and vertical circulation such as atriums, stairs, and elevators. Interstitial space is the volume above the ceiling to the underside of the floor above, constructed between any two occupied floors of a building that is dedicated to mechanical, electrical, and plumbing distribution systems. Interstitial space is not included in building gross area. However, areas of interstitial floors are calculated at 50% for building code purposes. Interstitial floors are structures to hold persons and MEP equipment and utility distribution systems.

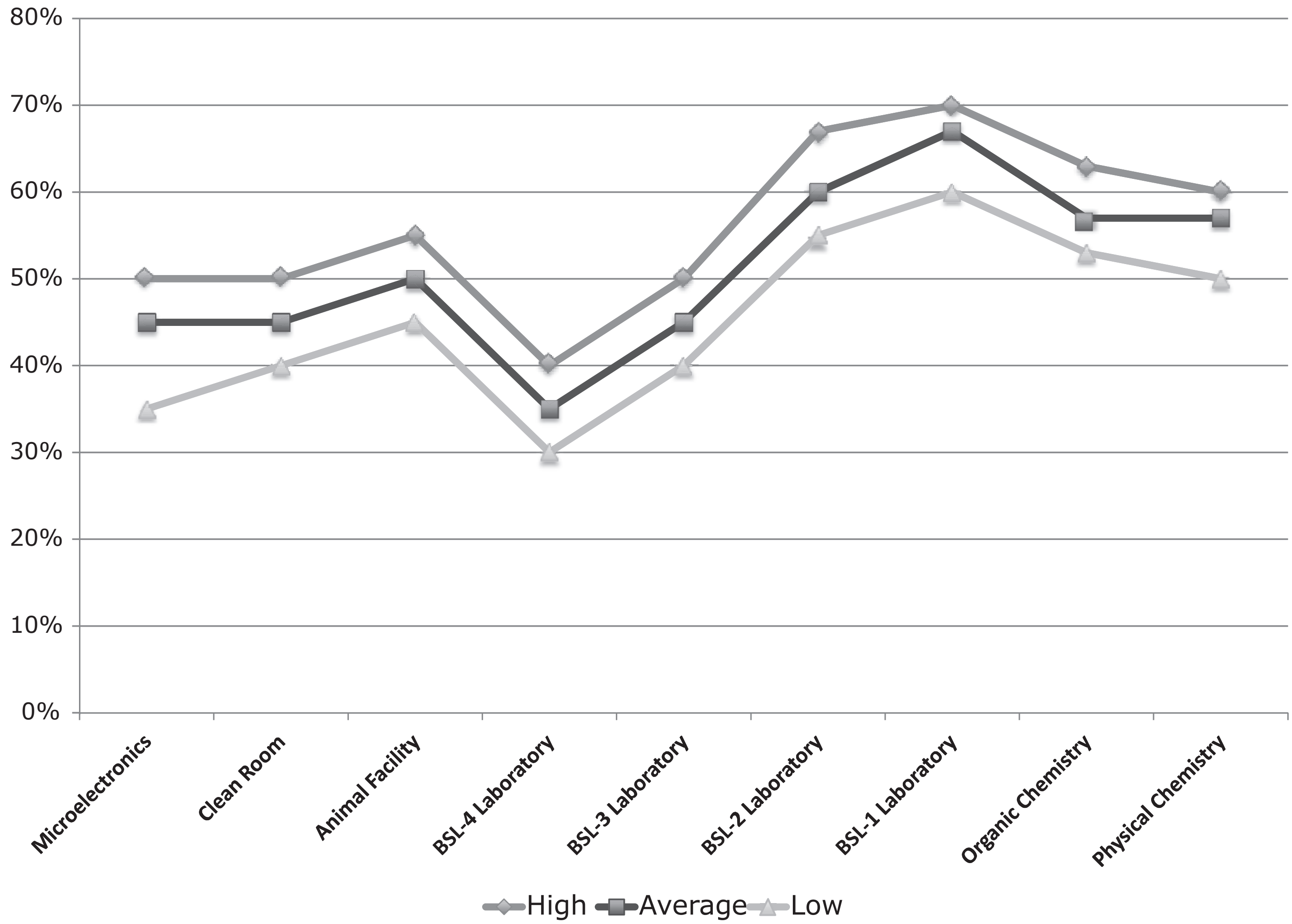

FIGURE 1-5. Range of net-to-gross ratios by laboratory type.

Total area calculations are determined as follows. Laboratory building configurations show variations of 60–85% net assignable laboratory area on a typical floor. Total net area must be converted to gross area to estimate the amount of actual building area that will be constructed to accommodate all the programmed functions on all floor levels. The conversion factor used to make this calculation is called the net-to-gross ratio. Net-to-gross ratios vary from 45% for animal facilities and intensive chemistry laboratory buildings with a high proportion of laboratory area—up to 70%—for efficient research laboratory buildings. Laboratories constructed in temperate and cold climates that have mechanical penthouses and often basements to accommodate all MEP/FP/IT equipment in a layout that allows ease of maintenance for complex systems. This area counts in gross area calculations. Microelectronics, biosafety laboratories at Levels 3 and 4, and other highly specialized and mechanically intensive buildings commonly have 30–45% net-to-gross ratios. These are efficient buildings too, but the nature of their functions requires a higher percentage of total area for special mechanical, HVAC, plumbing, and electrical systems (see Figure 1-5).

Buildings containing a low proportion of laboratories to nonlaboratory areas may achieve higher net-to-gross ratios. Some laboratory buildings do not have mechanical penthouses or expansive mechanical equipment rooms. When utilities such as steam, hot water, and process chilled-water are supplied from an external source, such as a central utility plant, these buildings experience higher net-to-gross ratios than laboratory buildings that are mechanically freestanding. Net-to-gross factors should be very carefully considered and conservatively estimated during the programming phase because they have a great impact on construction estimating and the design process following program completion.

Step 10: Spatial relationships of functions. The next task in developing outline and detailed functional programs is to inform the design architects and engineers of the important relationships between the parts of the building that are identified in the room list. Conceptual and outline building programs do not need to specify what is on every floor; that information is developed and organized later during the planning process. However, after the building site has been selected, conceptual floor plans may be shown in detailed functional programs. There are five sets of questions that have proven helpful to programmers and user groups for establishing important relationships between spaces and functions:

1. What is the organizational structure of the institution, corporation, or agency for which the building is being designed? Should room assignments and groupings reflect a hierarchy, or is some other pattern or principle preferred?
2. Do materials, processes, or waste products contained or produced in one area affect the function of, or pose a hazard for, any other area or function? If the answer is affirmative, what arrangements can be made to reduce or eliminate conflicts? Are appropriate rooms assigned to specialized waste handling and storage? Where should they be located with regard to the areas of waste generation, pathways used for waste removal, and supply air intakes? What are spatial considerations for stockrooms?
3. How close should laboratory support facilities be to the laboratories they serve? Are there critical relationships that affect health, safety, the environment, or efficiency?
4. Do certain laboratories, or the mechanical services to them, need to be isolated from other building functions or services for reasons of health and safety, or as a necessary part of their procedures and equipment operation?
5. How close should researchers' offices be to laboratories? Should offices be within laboratories, contiguous with laboratories, across the hall, in a separate wing or zone of the building? What are the health, safety, and efficiency implications of each location?

The last question generally brings up one of the more contentious issues in laboratory building planning. Some researchers insist that their offices be located in or immediately adjacent to their laboratories, whereas other researchers prefer to have their offices outside the laboratory zone. The caution is that offices in laboratory zones may be readily used by enterprising researchers for certain laboratory functions whether or not these offices are designed and equipped to safely support any laboratory function. Especially in academic settings, there is pressure on researchers to acquire new equipment or projects, even when appropriate laboratory space and funding for renovations are not available. Proximity of offices to laboratories usually dominates other criteria, such as adequate power, piped utilities, and appropriate ventilation. In the worst cases, offices adapted by researchers have additional power supplied by electric extension cords and piped utilities for gas and water by rubber tubing, strung across corridor ceilings from nearby laboratories. Offices have their doors propped open to improve ventilation by exhausting fumes into corridors and capturing more cool air for equipment that would otherwise overheat. Extremely serious health and safety hazards are generated by these kinds of unofficial and unsupervised construction adaptations made by researchers.

When offices are located in laboratory zones, whether across the hall from, adjacent to, or within laboratories, ventilation requirements for these offices should meet laboratory standards, in which general exhaust and 100% outside supply air are provided. In addition, electric panels should be sized to accommodate future increased power demands when offices are converted to laboratory use. There are higher initial construction costs to provide piped utilities and laboratory waste drains to offices, but if future flexibility and safety are priorities, it is a reasonable investment. These criteria should be included in the building program list of performance requirements.

Answers to these five questions provide additional information to assist the program project team to prepare a description of critical adjacencies that may be documented in text, charts, and diagrammatic floor plans. Figure 1-6 illustrates a matrix format, similar to that of a road mileage map, and Figure 1-7 shows a bubble diagram format that conveys adjacency information in a graphic fashion, representing, for this example, a clinical laboratory (discussed in Chapter 15).

Step 11: Basis of design. Basis of Design (BOD) in a laboratory facility program document is a "set of conditions, needs, and requirements taken into account in design of a facility" (*Business Dictionary*, www.businessdictionary.com). The BOD lists and describes the major components and systems of a building or renovation project. One major purpose of a BOD is to offer the owner a concise, but comprehensive narrative description of the proposed project. A second purpose is to provide the cost estimator with a summary of major scope components and systems for the building

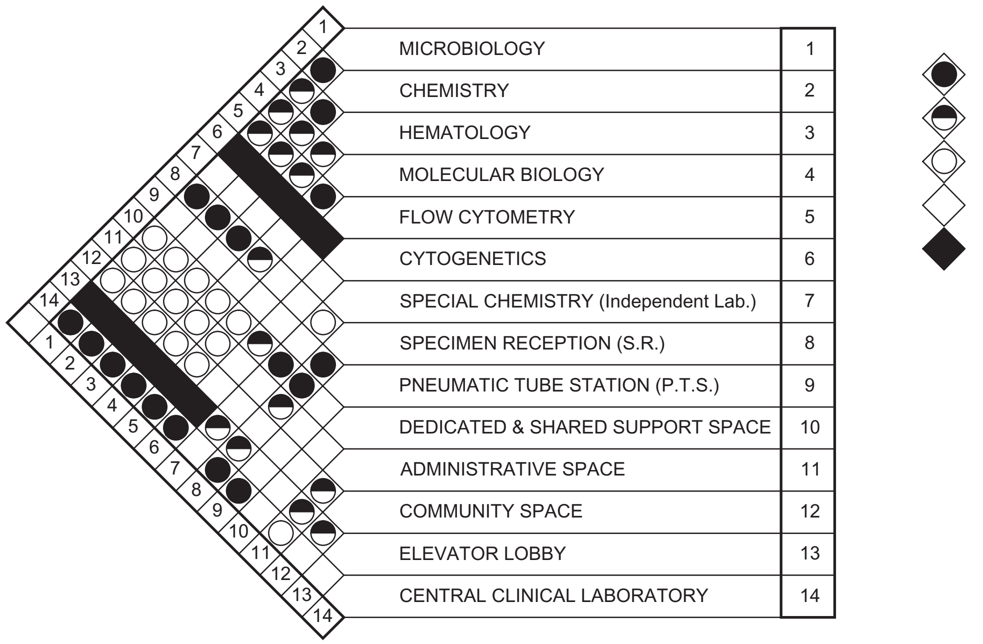

FIGURE 1-6. Adjacency matrix diagram.

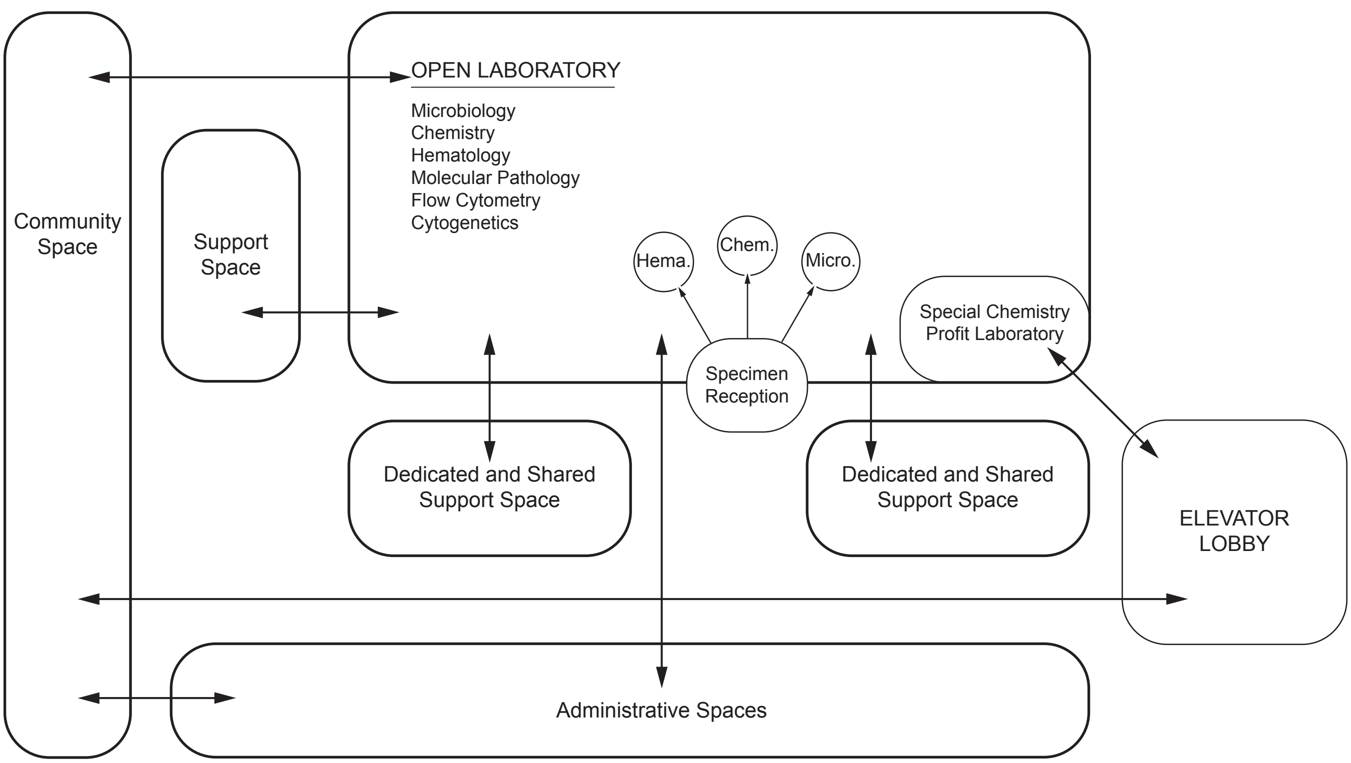

FIGURE 1-7. Adjacency bubble diagram.

TABLE 1-7. Some Components Included in the Design of Laboratory Buildings

Architectural	HVAC	Electrical
Exterior Enclosure	Heating System	Primary/ Secondary Feeds
Roofing System	Cooling System	Distribution Systems
Windows/ Glazing	Laboratory Ventilation	Emergency Power Equip
Interior Partitions	Control Systems	Standby Power Equipment
Interior Finishes	Filters	Control Systems
Special Features	Lab Chemical Hoods	Transformers
Safety Equip & Features	Energy Conservation	UPS & Line Conditioning
Structural	**Plumbing**	**Security & Alarms**
Foundation System	Hot Water System	Work Space Systems
Floor Framing System	Chilled Water System	Public Space Systems
Roof Framing System	Purified Water Sysem	Entry Control System
Seismic Force Strategy	Lab Piped Utilities	Control & Alarm Station
Stairs	Drainage Systems	Special Systems
Special Conditions	pH Neutralization	Audiovisual Equipment
Lighting	**Fire Protection**	**Safety Equipment**
Work Space Fixtures	Sprinkler System	Emergency Eye Wash
Public Space Fixtures	Fire Alarm System	Emergency Safety Shower
Control Systems	Fire Pump/ Standpipe	Chemical Storage Cabinets
Lamp Selections	Special Conditions	Fire Extinguishers

to facilitate generating the estimate. Table 1-7 is a sample list of some components included in a BOD for laboratory buildings.

STEP 12: COST MODEL OR ESTIMATE OF CONSTRUCTION AND PROJECT COSTS. The final task that may be considered for all program types is estimating the probable cost of construction, perhaps the most critical information the owner needs in a program document. Should an owner or administrative leaders set a construction budget without regard for the documented requirements and for the size and complexity of the project, success of the building's occupants, functions, safety, and its appropriateness will be put at risk. Unless the program project team—professional architects and engineers or an in-house team—has available to them extensive, up-to-date cost data on laboratory buildings, we recommend that well-qualified professional cost estimators should be hired to do this task. Professional cost estimators, with current, in-depth experience in laboratory building construction, can review the program description, whether conceptual, in an outline, or a BOD, in a detailed functional program, and develop a construction cost estimate. The estimator should be asked to provide design assumptions and the percent range of accuracy. A range of ±20 to 25% accuracy is not unusual during the programming phase because of construction market volatility and general economic factors. Figure 1-8 is a graph that shows relative construction costs for typical laboratory types. Software development laboratory construction cost is the base value of 1.0. Obviously, accuracy improves as the design phase proceeds, with development of plans, building engineering, and specifications. The owner's cost of the building includes many more categories of cost above construction cost, shown in Table 1-8. Construction cost alone comprises 50–75% of project costs in new construction and 30–80% of renovation projects.

1.2.1.3 Conclusion. For the design team, building programs contain comprehensive list of functions, performance specifications, and state the owners' goals. For building owners, building programs are documents against which building designs can be evaluated for adherence to the stated goals, functions, and specifications. To further assist the architects and engineers, the laboratory standard operating procedures and safety manuals used by the building occupants should accompany the building program to alert the design team to particular health and safety concerns of the owners and users. When such documents have not yet been prepared, borrowed manuals for similarly engaged facilities or appropriate sections of the present manual may be used for preliminary and basic guidance.

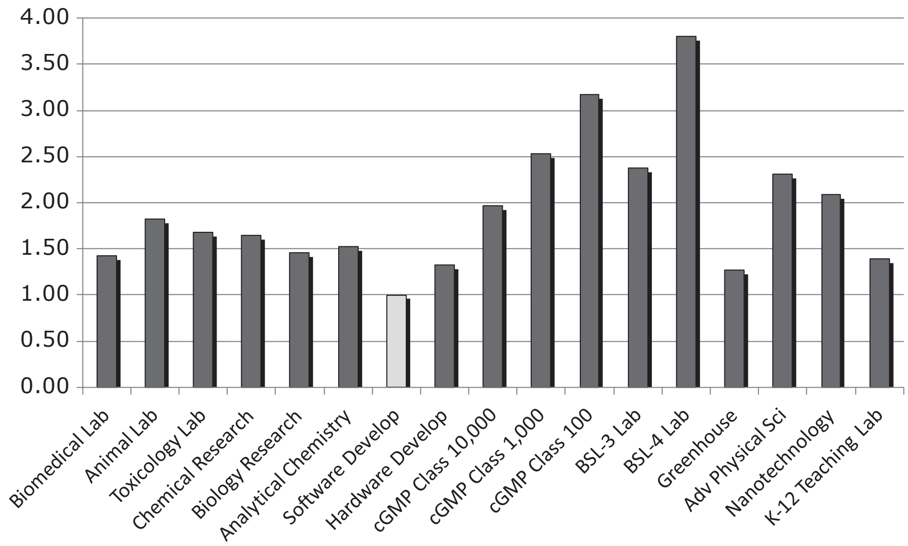

FIGURE 1-8. Cost index by laboratory facility type.

TABLE 1-8. Examples of Owner's Project Cost Components

Construction Cost	Legal Fees
Contingencies: Owner's, Design Changes, etc.	Owner's Management Services
Surveys: Site, EIS, Subsurface, Hydrology, etc.	Predesign Services Fees: Programming, Feasibility Study, Site Selection, etc.
Land Acquisition	Design Services Fees:
Permits: Utility Connection, Construction, Occupancy, etc.	Construction Management Fees
Site Development: Roads, Drainage, Utilities, Cut & Fill, Grading, etc.	Communications: IT Systems, Computer & Server Equipment, Wireless Network
Relocation & Reconnection of Utilities	Reimbursable Expenses
Landscaping (beyond 5 ft of building perimeter)	Interim Financing and Fees
Special Foundations & Subsurface Work	Cost Escalation
Hazardous Materials Remediation	Movable Equipment & Furnishings
Parking	NIC Fixed Equipment
Facilities for Temporary Relocation	Moving Expenses
Construction Cost	Legal Fees
Contingencies: Owner's, Design Changes, etc.	Owner's Management Services
Surveys: Site, EIS, Subsurface, Hydrology, etc.	Predesign Services Fees: Programming, Feasibility Study, Site Selection, etc.
Land Acquisition	Design Services Fees:
Permits: Utility Connection, Construction, Occupancy, etc.	Construction Management Fees
Site Development: Roads, Drainage, Utilities, Cut & Fill, Grading, etc.	Communications: IT Systems, Computer & Server Equipment, Wireless Network
Relocation & Reconnection of Utilities	Reimbursable Expenses
Landscaping (beyond 5 ft of building perimeter)	Interim Financing and Fees
Special Foundations & Subsurface Work	Cost Escalation
Hazardous Materials Remediation	Movable Equipment & Furnishings
Parking	NIC Fixed Equipment
Facilities for Temporary Relocation	Moving Expenses

Note. EIS = Environmental Impact Study; NIC = not in contract.

1.2.1.4 Transition to Design Phase – Traditional Process and Integrated Design Process. Traditional project design teams consist of architects and engineers, either in-house employees or contracted individuals or firms, and key owner's representatives, including environmental health and safety professionals (EH&S). To begin the planning process, project design teams use program documents and predesign studies that describe the scope of the project and project requirements to develop a schematic design. Throughout the planning and design process, the project design team engages laboratory users and occupants to obtain additional information, learn their preferences, and to make decisions. To obtain final decisions, the team meets with and makes periodic presentations to owner's representatives and user groups throughout the design development phase. After the team produces construction documents, interaction with users diminishes or ceases. Planning and design processes for new construction may take one year or more. The process duration is more variable for renovations, based on the area and complexity of the renovation, and the number of phases. See Chapter 3, Section 3.1.3 for more information on renovation project planning.

Over the past decade, a new integrated project design process (IPD) has evolved in the A/E/C industry (architecture/engineering/construction). The National Institute of Building Sciences in its *Whole Building Design Guide* (NIBS, 2012) offers strong recommendations and guidance for use of this new method. One major difference between a traditional design process and IPD is addition of a building construction or construction management team at the very beginning of the design process; they work with the traditional design team composed of architects, engineers, and their consultants. "The design of buildings requires the integration of many kinds of information into an elegant, useful, and durable whole. An integrated design process includes the active and continuing participation of users and community members, code officials, building technologists, contractors, cost consultants, civil engineers, mechanical and electrical engineers, structural engineers, specifications specialists, and consultants from many specialized fields. The best buildings result from continual, organized collaboration among all players. . . . The integrated design process enables project team members to work together from the project outset to develop solutions that have multiple benefits." (NIBS, 2012, p. 1) The phases of design (schematic design, design development, and contract documents) remain similar between traditional and IPD process, both start with programming described above in Section 1.2.1.2. "Regardless of a project's scope, research and programming is a crucial first step in developing a successful design. No later than the completion of these tasks should the client engage the architect or other prime consultant who will oversee the design process and its final implementation. . . Gradually a design emerges that embodies the interests and requirements of all participants, while also meeting overall area requirements and budgetary parameters. At this stage, schematic designs are produced" (NIBS, 2012, p. 1).

1.2.2 Planning

The end product of planning, the first phase of the design process, is a set of schematic design drawings, engineering systems descriptions, and outline specifications for materials to be used in construction. In a schematic design, architects customarily show the layout of each floor level and indicate circulation including egress pathways; they also present their initial concepts of what the building will look like, including the height, shape, volume, and primary materials of the enclosure. Schematic design drawings show locations on the site and site development for vehicular, service, and pedestrian entry points. From these drawings, engineers will prepare their estimated load calculations and make preliminary equipment selections. They will also develop concepts for all mechanical, electrical, and plumbing systems distribution, including fire protection, laboratory water, purified water, waste treatment, safety control systems, normal electrical service and IT systems, energy conservation, and emergency power. They will identify possible locations for primary equipment and mechanical rooms, as well as for utility distribution risers, air intakes and exhaust outlets, utility entry points, and sewage connection. The structural engineer will propose a structural system and grid of column and beam locations in the schematic design.

Schematic design drawings will show the size and location of every room listed in the building program by type and by floor level. This is a good time to develop a detailed layout of the generic modular laboratory (the basic spatial organizing unit of laboratory buildings) if it was not already proposed in the program document. Preliminary room and area assignments for the proposed occupants of the building may be shown on the schematic design drawings when the owner identifies the occupants.

The project design team should communicate intensively and frequently during the planning process to exchange information, to discuss issues brought forward by the generation of design ideas, to resolve problems that were not foreseen during the building program phase, and to make decisions. To establish effective lines of communication within the owner's entire group, a small committee should be designated to act as the owner's representative. The committee may include a few future laboratory users, PIs, supervisors and managers (along with other occupants if it is a mixed-use building), and facility management. It should also include EH&S professionals and key administrators. The leader of the building committee is an employee of the organization; to perform leadership responsibilities, this person should have the time officially authorized and the workload in his or her normal job commensurately reduced for the entire design phase. On a day-to-day basis, the leader receives informal oral and official written communications from the project design team then distributes this information to the building committee and directly to specific users, to elicit their opinions on issues or design decisions under consideration. This is an iterative process and requires participation of the stakeholders, not surrogates, to make it work well. Construction is disruptive, even disturbing, to technical people with previously well-established locations and routines. There is a "churn cost" involved in moving or relocating people, even to superior facilities. Regular and specific communications during design and through construction can go far to reducing the tensions of change.

In the schematic design phase, options in planning, laboratory layouts, building mechanical systems, and architectural design should be explored because the project design team is still creating it. Things tend to lock up increasingly after this point. In the phase that follows, called *design development*, the project design team will develop greater detail and clearer definition of the agreed-upon concept. This process leads to the final design, so opportunities for major design changes diminish dramatically as the design development phase ends.

Cost estimators usually provide estimates at the conclusion of each design phase, including schematic design and design development. Adjustments in building area, quality of materials, or methods of construction are generated during these phases to keep the project within budget. Late changes and afterthoughts brought to the design team during the construction document phase are expensive to execute and time-consuming; they put the project schedule at risk with increased costs.

1.2.2.1 Building Spatial Organization. While the architect designs the optimal building enclosure configuration, site location, and image, the project design team will also generate concepts for the internal organization of the building spaces and infrastructure. The internal organization of a laboratory building is comprised of six major patterns of spatial definition:

1. Circulation of people and materials (Section 1.2.3)
2. Generic laboratory modules (Section 1.2.4)
3. Distribution of mechanical equipment and services (Section 1.2.5)
4. Structural system (Section 1.2.6)
5. Site regulations (Section 1.2.7)
6. Building enclosure configuration (Section 1.2.8)

The project design team must consider these patterns of spatial definition together during the planning phase and thoroughly coordinate them during all later design phases. Although structural and mechanical engineers can design many solutions to fit building enclosures, a comprehensive engineering concept is needed in the schematic phase to fulfill building performance requirements and provide optimal solutions for function, safety, and flexibility. All systems should complement one another to provide a safe and healthful work environment efficiently and at reasonable cost. Drawing techniques, such as those available in computer-aided design and drafting (CADD) and three-dimensional representation methods, allow superimposition of the design layouts prepared by mechanical and electrical engineers upon those prepared by the architects and structural engineer to detect physical conflicts. Some building information management (BIM) computer programs do this process in dimensions and also create a comprehensive building database. This helps create well-coordinated construction documents. Ultimately, the compatibility of all of the systems that will define the facility depends on the expert knowledge and creativity of the project design team.

1.2.3 Circulation of People and Materials

For legal and safety reasons, how people and materials circulate within and around the laboratory building are vital concerns. The designer must consider building code requirements, accessibility needs, and transport of hazardous materials.

1.2.3.1 Building Code Considerations. Health and safety issues of circulation are primarily concerned with (1) emergency egress of building occupants, and (2) access to the building and its internal parts by emergency personnel, such as hazardous materials response officers, fire fighters, and police officers. Building codes regulate these issues (Baum, 2005, provides good background on this topic). The major reference sources used in this book are the International Building Code (IBC, 2012), the International Fire Code (IFC, 2012), the National Fire Protection Association's Life Safety Code 101 (NFPA, 2012), the Occupational Safety and Health Administration's (OSHA) Laboratory Standard 1910.1450 (2013), and Standard 29CFR 1910.1200 App E (OSHA, 2013), and the Americans with Disabilities

Act (ADA, 1990). The latest editions of these laws, codes, and standards define and specify all the components for building egress and access that pertain to occupant safety. Specific sections of note are the following:

- International Building Code (2012): Chapter 3, "Use and Occupancy Classification," and Chapter 10, "Means of Egress."
- NFPA Bulletin 101 (2012): Life Safety Code, Section 1.12, "Danger to Life from Fire," and Section 1.1.3, "Egress Facilities."
- OSHA Health and Safety Standards (2011): 29 CFR 1910.35, Chapter XVII, Subpart E, "Means of Egress."
- Americans with Disabilities Act of 1990, amended in 2008: 28 CFR, Title III, Part 36, "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities, Final Rule"; Subpart D, "New Construction and Alterations"; Paragraph 4.3, "Accessible Route"; and Paragraph 4.3.1.0, "Egress."

Historically recognized building codes in the United States include the Building Code Officials' Association (BOCA) Code, the Uniform Building Code (UBC), and the Southern Building Code Congress International (SBC). Although these older codes are no longer published, many existing buildings were designed to their specifications. For renovations and building additions, project designers must go back to these codes to judge the conditions that are newly relevant. Past editions of these codes are available online. The International Building Code (IBC, 2012) is the most current code referenced in this edition. State and city codes also address building circulation conditions, occupant egress, and emergency responder access. Requirements in other current codes may differ somewhat from the specific IBC citations referred to in this book, but they take precedence when they are more restrictive or are adopted by the jurisdiction having authority.

1.2.3.1.1 International Building Code Requirements. Chapter 10, Section 1003, "Means of Egress" (IBC, 2012) shows the general requirements, such as minimum ceiling and door heights, vertical and horizontal projections into the egress pathway, and means of egress continuity. People usually flee a building by corridors and stairs. Section 1004 discusses occupant load. It is important that egress pathways are wide enough to allow building occupants to exit safely under normal and emergency conditions. According to the occupancy use selected for laboratory buildings discussed in IBC (2012) Chapter 3, " Use and Occupancy Classifications," laboratory building occupant load can be calculated at 50 net ft^2 (4.65 m^2) per occupant in buildings classified as Educational Group to 100 gross ft^2 (9.3 m^2) per occupant classified as a Business Group. See Table 1004.1.1, "Maximum Floor Area Allowances per Occupant" and Table 1005.1, "Egress Width per Occupant Served" (IBC, 2012) for all occupancy groups. Per the IBC, Educational Group pertains to educational facilities only up to grade 12 (IBC, 2012). Laboratory is not a classified building use in the IBC (2012). The great majority of higher education, corporate, and government agency laboratories are classified in Business Group 'B' (IBC, 2012). Other special-risk laboratory buildings may be classified in High Hazard Group 'H' (IBC, 2012). Section 1.2.4.2 contains details of use and occupancy classification and an adaptation of Table 1004.1.1 in the IBC (2012).

The IBC sets requirements for exit door and egress pathway widths based on the occupancy load and upon whether the laboratory building is protected by an automatic sprinkler system. We recommend installation of automatic sprinkler systems in laboratory buildings; Section 1007 of the IBC (2012) explains the requirements for accessible means of egress.

1.2.3.1.2 Accessibility Guidelines. Ease of access and emergency evacuation for disabled persons merit special attention. The Americans with Disability Act of 1990, 28 CFR, Title III, Part 36 (ADA, 2008) describes and discusses specific issues of accessibility and safety for disabled persons in commercial facilities, which may include laboratories. The act contains extensive guidelines on design standards that are based, in part, on ANSI Standard A117.1-2003, "Usability for Physically Handicapped People" (ANSI, 2003). As with building codes, state and local jurisdictions may require more stringent standards for accessibility; the project team must check to make sure that new construction, additions, or renovations comply if the laboratory building is in the category of "public accommodation." Private commercial and industrial laboratories in certain aspects may have fewer accessibility requirements if no disabled persons are employed there currently. However, in the future they may need to comply with the ADA. Buildings that are accessible facilitate employment of disabled persons and their integration into the science and engineering workforce. No architectural barriers should be designed and constructed at main entrances, doorways, public toilet rooms, elevators, drinking fountains, public telephones, or other public accommodations within laboratory buildings.

Standards for accessible design are upgraded regularly. In general however, the clear floor area required for persons in wheelchairs to turn around is a circle with minimum 5 ft (1.5 m) diameter. The maximum slope on ramps in public corridors or for access to special laboratories with raised floors is 1:12. Ramps must be structured to safely carry the live load of persons and materials using them. Door minimum clear width opening is 32 in. (81 cm). The preferred minimum door width in good laboratory design is 36 in. (91 cm). There also must be adequate clearances on both sides of swinging doors on the latch side with 1.5 ft (46 cm) minimum, 2.0 ft (61 cm) preferred on the in-swinging side and 1 ft (30 cm) on the out-swinging side. Laboratory building design should incorporate all basic access accommodations for all public pathways, doorways, and public facilities to avoid high costs of future retrofits.

Surrogates for visible signs, highly legible signs, and acceptable door and elevator hardware should be provided for those who are visually impaired. Alarms, warnings, and controls detectable by both disabled and unimpaired people are required by code, as well as by ADA. See Chapter 2, Section 2.2.2.4 for details of accessibility in laboratory design.

1.2.3.1.3 Transport of Hazardous Materials. Laboratory buildings may contain a wide variety of hazardous materials, as listed and described in Chapter 2, Sections 2.4.5 and 2.4.6, as well as in Chapter 27, Section 27.1. Laboratory occupants, trained EH&S staff persons, and external vendors transport these materials to and from laboratories, laboratory support rooms, and support spaces such as mechanical equipment and pump rooms. People must be able to safely deliver hazardous materials and then remove hazardous waste from locations ranging from penthouses down to subbasements, where mechanical equipment is located that must be maintained. Materials movement is safer using clear, unobstructed horizontal pathways of sufficient width to negotiate turns easily. People pushing lab carts, handtrucks, and dollies, which move well on smooth, level, horizontal pathways, have difficulty with ramps, narrow corridors and doorways, raised thresholds, and hard-to-open doors. Keep these impediments out of the design and detailing of floors and doors. Clearance requirements may be more specific for motorized material-handling equipment than for manual equipment.

Vertical pathways, including stairs and elevators, increase risk of breakage and spills of transported hazardous materials. We highly recommend service elevators in multilevel laboratory buildings for transport of hazardous materials. Passenger elevators should not be used for transport of hazardous materials. Service elevators that access penthouses and subbasements are critical for maintenance personnel and operations. Service elevators with restricted, keycard access can be used to safely transport vessels containing cryogenic liquids and gas cylinders. Many jurisdictions prohibit the use of passenger elevators for transporting these materials. When this type of hazardous material is in a service elevator cab, people should not ride in the cab. One person loads the elevator on one level, and another person receives and removes the hazardous material at the destination level. This method avoids the risk of asphyxiation of persons in the elevator cab. See Section 2 of Chapters 17, Gross Anatomy Laboratory; Chapter 19, Autopsy Laboratory; Chapter 20, Morgue Facility; and Chapter 22, Animal Research Laboratory for other service elevator considerations for these laboratory.

Laboratory workers may choose to use stairways if they are hand-carrying small, lightweight trays or boxes containing hazardous materials, and if service elevators are in inconvenient locations. Workers should use secondary containment trays to capture spills and sealed containers if the carried vessels break or tip over.

1.2.3.2 Common Circulation Configurations. Laboratory buildings commonly have four personnel and materials' handling configurations: (1) single corridor, double-loaded; (2) internal loop corridor; (3) perimeter loop corridor; and (4) corridor grid. Supplementary approaches include service corridors and finger corridors. Figures 1-10 to 1-14 show examples of these common circulation configurations and variations with supplementary circulation.

Table 1.9 presents pros and cons of common corridor configurations. We do not recommend one over the other; there is not a right or wrong pattern. Evaluating facility safety circumstances and access requirements will help the design team to determine the best choice.

1.2.3.2.1 Single Corridor. Buildings with single corridors are simple and efficient. Both ends of single corridors generally have emergency egress doors and/or fire stairs to evacuate the building according to code. Elevator cores may be any location along the corridor. Centered single corridors, shown in Figure 1-9A, generally provide space for laboratories along both sides of buildings. Single corridors offset from center can provide layouts with laboratories on one side and offices or other functions on the other, as shown in Figure 1-9B. Single-corridor building layouts such as Figures 1-9B and 1-9C can fit on narrow sites.

1.2.3.2.2 Internal Loop Corridor. Internal loop corridor options are shown in Figures 1-10A and 1-10B. As the name implies, these corridors wrap around building center core spaces and provide access to laboratories and offices on two to four sides of the building. When supplementary corridors cross the center core, shown in Figure 1-10B, providing convenient shortcuts for occupants, positive interaction between occupants on both sides of the building increases. Some shared laboratory

TABLE 1-9. Comparison of Circulation Patterns in Laboratory Buildings

	Circulation Patterns			
	Single	Racetrack	Perimeter	Grid
PROS				
1	Highest efficiency			
2	Double-loaded, high efficiency	Double-loaded, high efficiency		Double-loaded, high efficiency
3	Occupant interaction increases			
4			Separate service corridor possible	Separate service corridor possible
5			Lots of exterior windows in corridor	
6	Exterior windows in labs/ ofcs	Exterior windows in labs/ ofcs	No exterior windows in labs/ ofcs	Exterior windows in labs/ ofcs
7		Wide floorplate possible	Wide floorplate possible	Extra-wide floorplate possible
CONS				
1		Lower efficiency	Lower efficiency	Lowest efficiency
2			Single-loaded, low efficiency	
3		Occupant interaction lower	Occupant interaction lower	Occupant interaction lower
4	No service corridor possible	No service corridor possible		
5	Very few exterior windows in corridor	Very few exterior windows in corridor		Very few exterior windows in corridor
6			No exterior windows in labs/ ofcs	Few exterior windows in labs/ ofcs
7	Difficult to get wide floorplate			

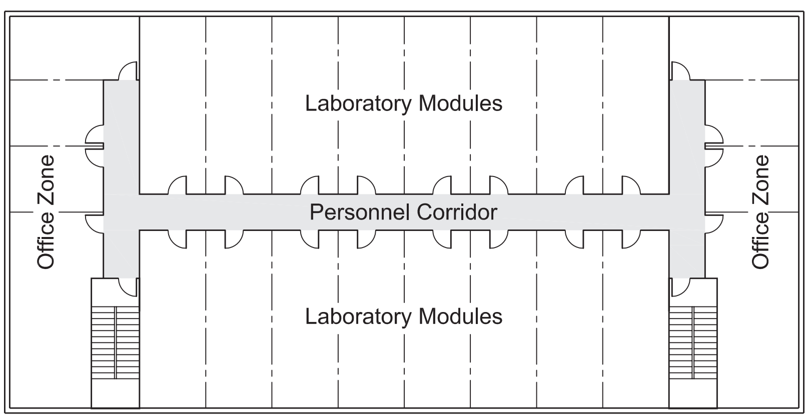

FIGURE 1-9A. Single center corridor, building layout.

support functions may have entry doors on both ends, again allowing easy access for occupants on both sides of the building.

1.2.3.2.3 Perimeter Loop Corridor. Figure 1-11A shows a perimeter loop corridor wrapping around the building at the exterior wall on at least two sides. At the ends of some buildings, perimeter corridors may move inward from the exterior wall, as shown in Figures 1-11A and B. Because perimeter loop corridors can have lots of window area, Figure 1-11C shows the corridor on one side is widened to accommodate an open office layout. The perimeter corridor on the opposite side can be used for public access or for service functions. This design

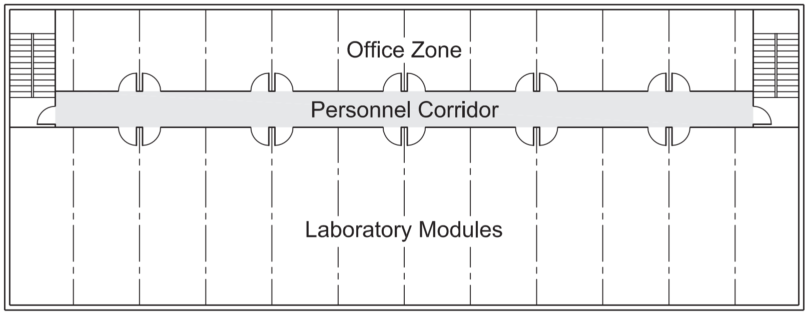

FIGURE 1-9B. Single offset corridor, building layout.

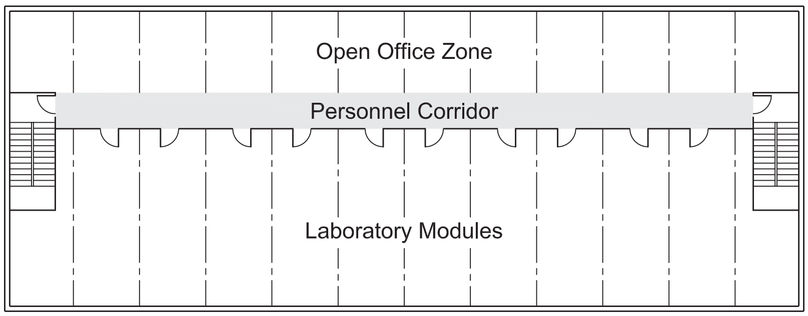

FIGURE 1-9C. No-corridor building layout.

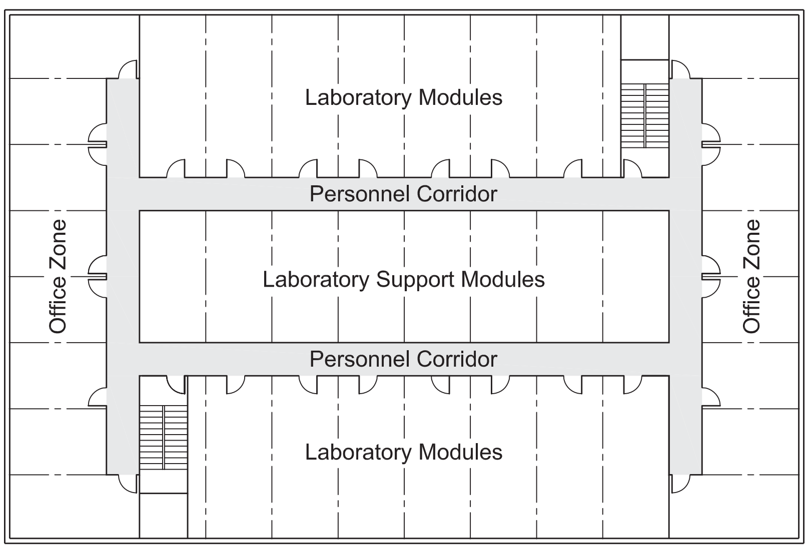

FIGURE 1-10A. Internal loop corridor with core, building Layout.

allows laboratory occupants' desk space to be proximate to, but still outside of the laboratories. Supply air is provided to corridors, and that air passes into the laboratory zone due to laboratories' slight negative pressurization. Figure 1-11D shows a perimeter loop corridor layout that includes a central service corridor to improve flexibility for laboratory changes.

1.2.3.2.4 Grid Corridor System. Grid corridors allow easy access to all parts of buildings with large, wide floor plates. Grids are used when a large percentage of laboratory and building functions do not require windows for access to natural light and views, such as shown in Figure 1-12. Good signage is important in buildings with grid corridor systems because a network of corridors

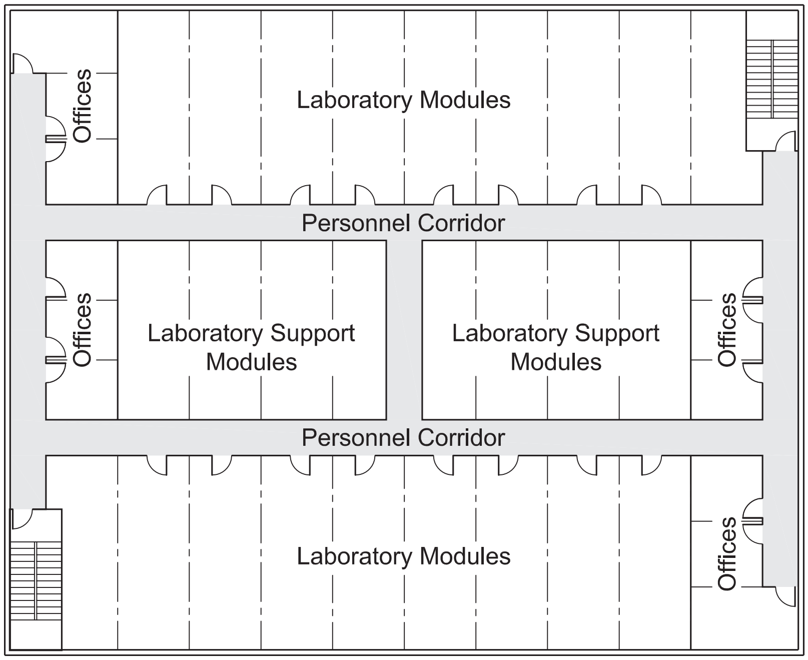

FIGURE 1-10B. Internal and perimeter loop corridors, building layout.

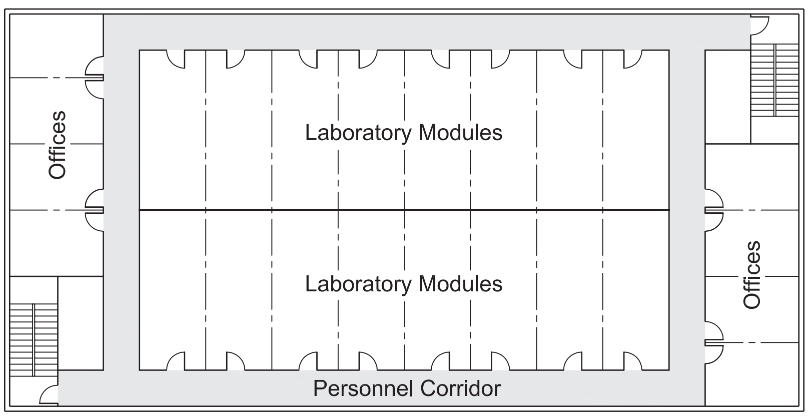

FIGURE 1-11A. Combination loop corridors, building layout.

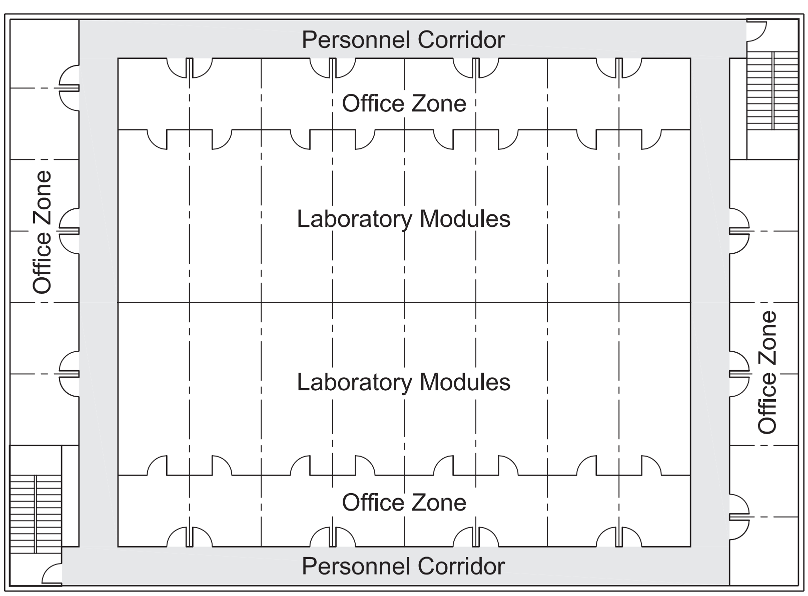

FIGURE 1-11B. Combination loop corridors, building layout.

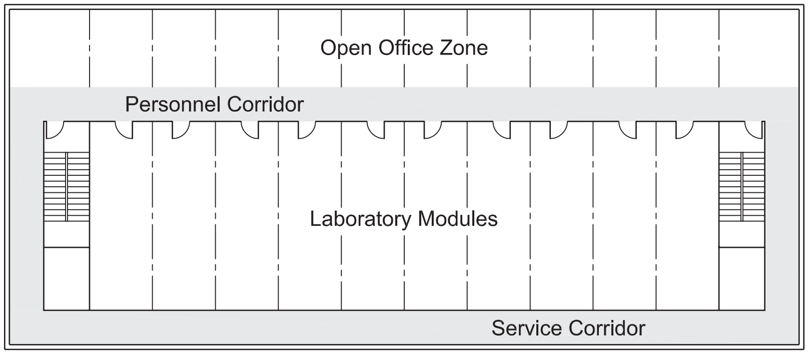

FIGURE 1-11C. Combination loop corridors with open office zone, building layout.

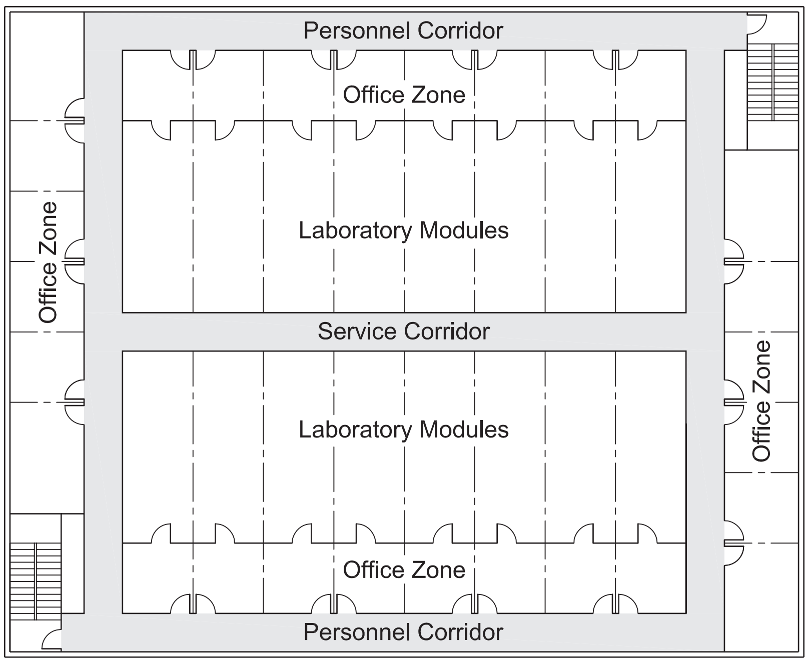

FIGURE 1-11D. Combination loop with center service corridors, building layout.

can be very disorienting to new building occupants and visitors.

1.2.3.2.5 Service Corridor. Service corridors are restricted access pathways, used by scientists, technicians, EH&S, transport, and maintenance personnel. Service corridors are normally designed for building plans that use perimeter and grid corridors. Laboratory exhaust air ducts are supported from the structure above and enter laboratories through walls enclosing service corridors. Figure 1-11D shows a layout that permits servicing of pipes and ducts inside vertical shafts or mounted directly upon service corridor walls outside laboratories, greatly reducing the frequency of and risks to maintenance personnel having to enter laboratories. If service corridors' walls are constructed with fire-resistive assemblies and according to building code, they can also provide secondary egress pathways from each laboratory and among separate fire zones.

1.2.3.2.6 Finger Corridors. Finger corridors, as illustrated in Figure 1-13, can be designed for building plans that use primary single corridors that are double-loaded, or internal loop corridors. All building codes restrict the lengths of finger corridors because code officials regard them as dead-end corridors, even if technically, finger corridors have second exits. Under normal conditions, the maximum length is 20 ft (6 m). For laboratory buildings wider than 75 ft (23 m), adding finger corridors, entered from the single central corridor, can offer public

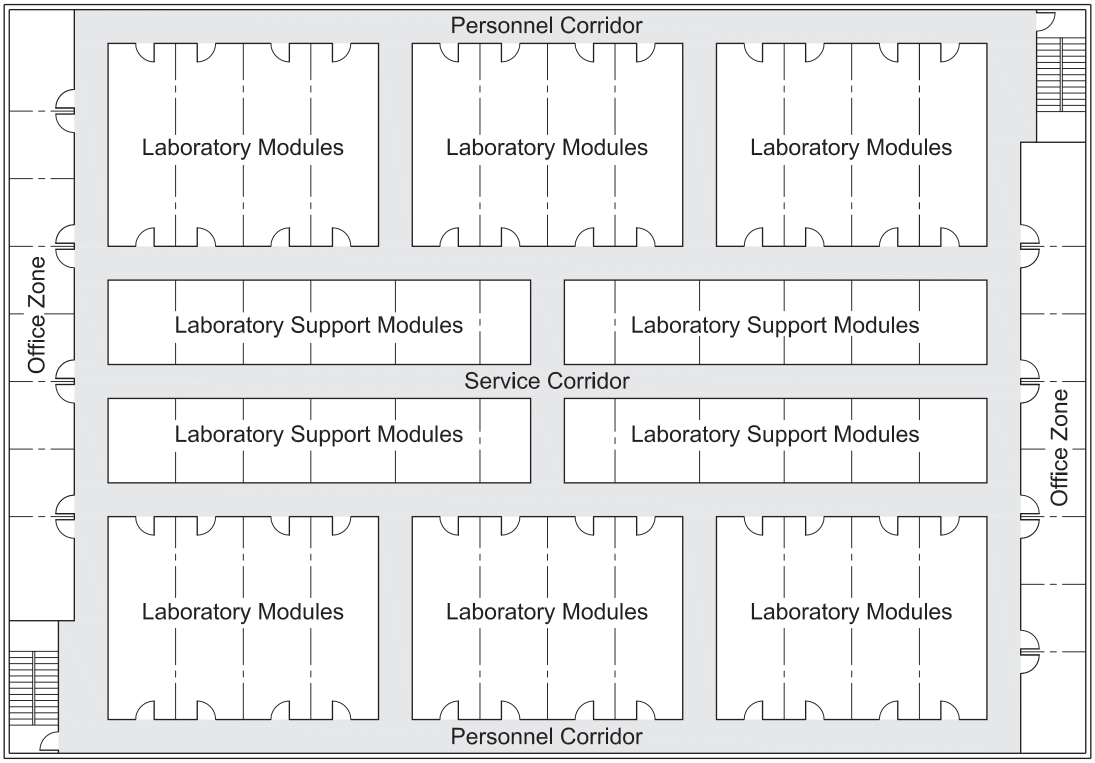

FIGURE 1-12. Grid corridor system, building layout.

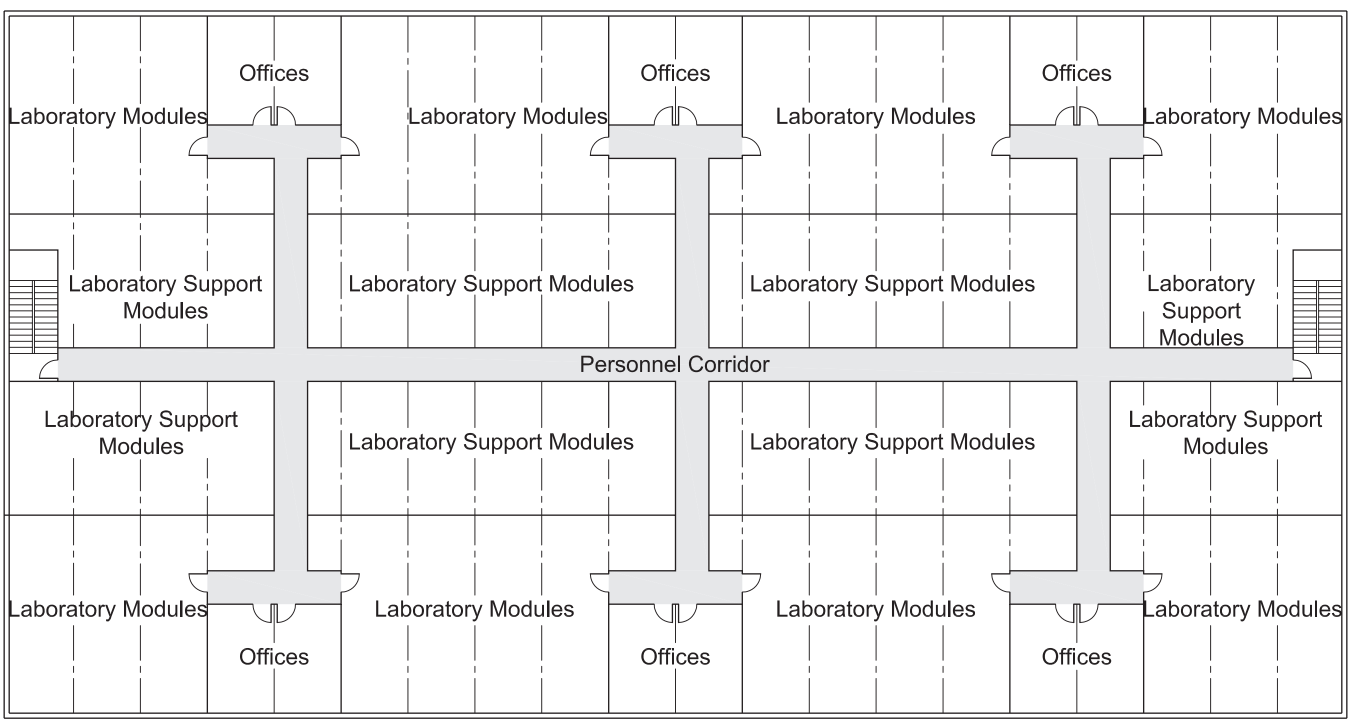

FIGURE 1-13A. Wide floor plate with finger corridors, building layout.

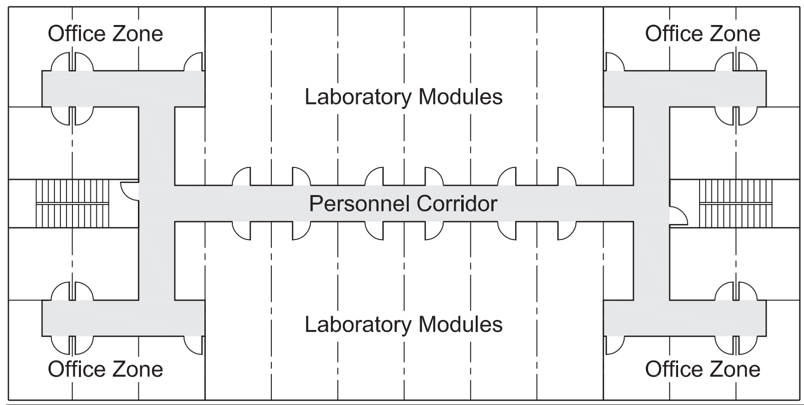

FIGURE 1-13B. Narrow floor plate with finger corridors, building layout.

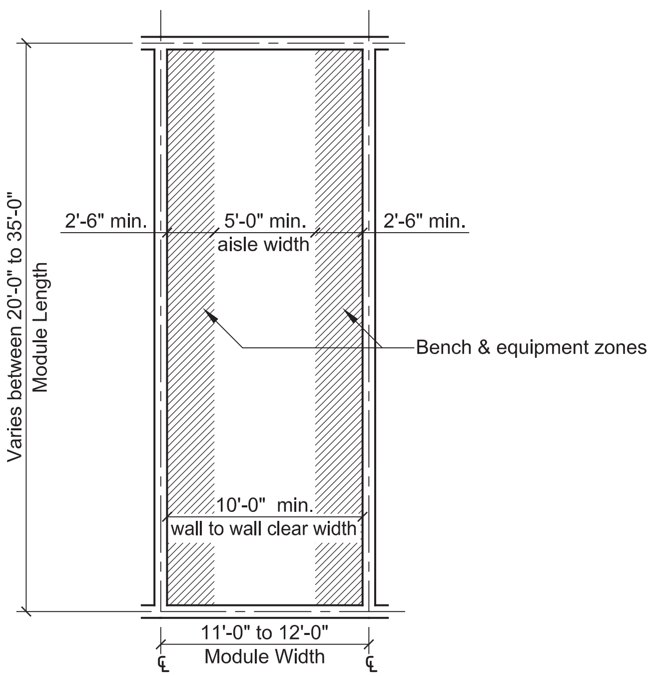

FIGURE 1-14. Single laboratory module diagram.

access to support functions and offices that otherwise would force primary access through laboratories, an access that is not recommended.

1.2.4 Laboratory Module

In Section 1.2.1.2.1, Step 7 shows how to use module areas for generating a laboratory program. The plans above show that using a modular approach to planning laboratories is efficient, and the resulting laboratories are more flexible because they have common dimensions. A single laboratory module is defined as a basic unit of space of a size commonly referred to as a *two-person laboratory* (Figure 1-14). Formulation of the internal organization of the laboratory building begins with a decision on the dimensions of the standard or generic laboratory module and the occupancy density. This task redirects the planning focus from the large scale of the total facility down to the small scale of a single laboratory module, the basic working area generally for one to three laboratory occupants. Chapter 2, Section 2.2.1 has information on laboratory module size and proportions.

1.2.4.1 Laboratory Unit. The National Fire Protection Association, Standard 45, Fire Protection for Laboratories Using Chemicals (NFPA, 2011), defines a laboratory unit as "an enclosed space used for experiments or tests." It may be an assembly of a number of laboratory modules, corridors, contiguous accessory spaces, and offices into this larger space category—the laboratory unit. See the definition of departmental gross area in Section 1.2.1.2.1. Step 9, which has some similarity to the definition of laboratory unit. Under NFPA 45 (2011), entire buildings may be defined as a single laboratory unit. This standard offers criteria for planning laboratory units (Standard 45, NFPA, 2011). The IBC (2012) does not use the term laboratory unit to categorize laboratory space.

1.2.4.2 Building Code Allowable Chemical Limits. In strong contrast to NFPA standards 45 and 101, the IBC (2012) has lower limits for volumes and weights of chemicals in laboratory buildings under Business (B), Educational (E), or Institutional (I) use and occupancy groups. Allowable limits are given in Table 307.1 (1), "Maximum Allowable Quantity per Control Area of Hazardous Materials Posing a Physical Hazard" (IBC, 2012). Table 1-10 has been adapted from IBC Table 307.1(1) (IBC, 2012). The IBC (2012) limits total allowable volumes of hazardous materials on each floor or in specific fire control areas on each floor, and in the entire

TABLE 1-10. Adapted from IBC (2012) Table 307.1(1) Maximum Allowable Quantity per Control Area of Hazardous Materials Posing Physical Hazard

MATERIAL	CLASS	Group when the Maximum Allowable Quantity is Exceeded	STORAGE						USE CLOSED SYSTEMS						USE OPEN SYSTEMS			
			Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes
Combustible Liquid[c, j]	**II**	**H-2 or H-3**	NA		**120**	a, b	NA		NA		**120**	a	NA		NA		**30**	a
	IIIA	**H-2 or H-3**			**330**	a, b					**330**	a					**80**	a
	IIIB	**NA**			**13,200**	b, c					**13,200**	c					**3,300**	c
Combustible Fiber	**Loose**	**H-3**	**(100)**		NA		NA		**(100)**		NA		NA		**(20)**		NA	
	Baled		**(1000)**						**(1000)**						**(200)**			
Cryogenics, Flammable	**NA**	**H-2**	NA		**45**	a	NA		NA		**45**	a	NA		NA		**10**	a
Cryogenics, Oxidizing	**NA**	**H-3**	NA		**45**	a	NA		NA		**45**	a	NA		NA		**10**	a
Flammable Gas	**Gas**	**H-2**	NA		NA		**1,000**	a, b	NA		NA		NA		NA		NA	
	Liquid				**30**	a, b	NA				**30**	a, b						
Flammable Liquid[c]	**1A**	**H-2 or H-3**	NA		**30**	a, b	NA		NA		**30**	a	NA		NA		**10**	a
	1B, 1C				**120**	a, b					**120**	a					**30**	a
Combined Flammable Liquid (1A 1B 1C)	**NA**	**H-2 or H-3**	NA		**30**	a, b	NA		NA		**30**	a	NA		NA		**10**	a
					120	a, b					**120**	a					**30**	a
Flammable Solid	**NA**	**H-3**	**125**	a, b	NA		NA		**125**	a	NA		NA		**25**	a	NA	
Pyrophoric Material	**NA**	**H-2**	**4**	b, d	**(4)**	b, d	**50**	b, d	**1**	d	**(1)**	d	**10**	b, d	**0**		**0**	**0**
Organic Peroxide	**UD**	**H-1**	**1**	b, d	**(1)**	b, d	NA		**0.25**	d	**(0.25)**	d	NA		**0.25**	d	**(0.25)**	d
	I	**H-2**	**5**	a, b	**(5)**	a, b	NA		**1**	a	**(1)**		NA		**1**	a	**(1)**	a
	II	**H-3**	**50**	a, b	**(50)**	a, b	NA		**50**	a	**(50)**	a	NA		**10**	a	**(10)**	a
	III	**H-3**	**125**	a, b	**(125)**	a, b	NA		**125**	a	**(125)**	a	NA		**25**	a	**(25)**	a
	IV	**NA**	NL		NL		NA		NL		NL		NA		NL		NL	
	V	**NA**	NL		NL		NA		NL		NL		NA		NL		NL	
Oxidizer	**4**	**H-1**	**1**	b, d	**(1)**	b, d	NA		**0.25**	d	**(0.25)**	d	NA		**0.25**	d	**(0.25)**	d
	3	**H-2 or H-3**	**10**	a, b	**(10)**	a, b	NA		**2**	a	**(2)**	a	NA		**2**	a	**(2)**	a
	2	**H-3**	**250**	a, b	**(250)**	a, b	NA		**250**	a	**(250)**	a	NA		**50**	a	**(50)**	a
	1	**NA**	**4,000**	b, c	**(4,000)**	b, c	NA		**4,000**	c	**(4,000)**	c	NA		**1,000**	c	**(1,000)**	c
Oxidizing Gas	**Gas**	**H-3**	NA		NA		**1,500**	a, b	NA		NA		**1,500**	a, b	NA		NA	
	Liquid		NA		**15**	a, b	NA		NA		**15**	a, b	NA		NA		NA	

(Continued)

TABLE 1-10. (*Continued*)

MATERIAL	CLASS	Group when the Maximum Allowable Quantity is Exceeded	STORAGE						USE CLOSED SYSTEMS						USE OPEN SYSTEMS			
			Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes
Unstable Reactive	**4**	**H-1**	**1**		**(1)**		**10**		**0.25**		**(0.25)**		**2**		**0.25**		**(0.25)**	
	3	**H-2 or H-3**	**5**		**(5)**		**50**		**1**		**(1)**		**10**		**1**		**(1)**	
	2	**H-3**	**50**		**(50)**		**250**		**50**		**(50)**		**250**		**10**		**(10)**	
	1	**NA**	NL		NL		NL		NL		NL		NL		NL		NL	
Water Reactive	**3**	**H-2**	**5**		**(5)**		NA		**5**		**(5)**		NA		**1**		**(1)**	
	2	**H-3**	**50**		**(50)**		NA		**50**		**(50)**		NA		**10**		**(10)**	
	1	**NA**	NL		NL		NA		NL		NL		NA		NL		NL	

Notes: 1 Cu Ft = 0.023 m^3; 1 lb = 0.454 kg; 1 Gallon = 3.785 L; NL = not limited; NA = not applicable; UD = unclassified detonable.

[a]Maximum allowable quantities shall be increased 100% in buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 of IBC (2012). Where not "e" applies, the increase for both notes shall be applied accumulatively.

[b]Maximum allowable quantities shall be increased 100% when stored in approved storage cabinets, day boxes, gas cabinets, exhausted enclosures, or safety cans. Where Note "d" also applies, the increase for both notes shall be applied accumulatively.

[c]The permitted quantities shall not be limited in a building equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 of IBC (2012).

[d]Permitted only in buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 of IBC (2012).

building—no matter the size of the floor or building. IBC Section 414, paragraph 414.2 (IBC, 2012) defines a control area as "a building or portion of a building within which the exempted amounts of hazardous materials may be stored, dispensed, handled or used." Fire control area requirements for fire-rated assemblies are described in IBC, Section 414.2 (2012) as well. IBC Table 307.1(2), Maximum Allowable Quantity per Control Area of Hazardous Materials Posing a Health Hazard (IBC, 2012), applies to other categories of hazardous chemicals. See Table 1-11 which has been adapted from IBC Table 307.1(2).

The IBC (2012) Table 414.2.2 shows the number of fire control areas allowed per floor level and the percentage of hazardous materials allowed on each level. Figure 1-15 shows a graphic representation of the control area concept for laboratory buildings. IBC does not depend on fire-hazard classifications for laboratories, just allowable chemical volumes to guide laboratory planners. This is another reason why collecting chemical inventories for each laboratory, as well as for the entire building, is important to complete in the programming phase, as noted in Section 1.2.1.2.1, Step 6.

Laboratory buildings that will exceed the maximum allowable quantities per control area of hazardous materials, as shown in Tables 1-10 and 1-11, fall into the High Hazard Group (H) use and occupancy classification as defined in IBC, Section 307 (IBC, 2012) and IFC, Section 415 (IFC, 2012). Group H is handled as a separate classification because it represents an unusually high degree of hazard that is not found in the other occupancies. It is important to isolate industrial or storage operations that pose the greatest dangers to life and property and to reduce their hazards by incorporating protective measures described in the regulatory provisions of building codes. The classification of a material as high hazard is based on information derived from the U.S. Code of Federal Regulations (DOL 29 CFR; IBC, 2012, Section 307) and NFPA standards.

There are five categories of Group H occupancies. Group H-5 was generated by the semiconductor industry to address acute hazards from hazardous production material (HPM) facilities, as discussed later in Chapter 23, Microelectronics and Cleanroom Laboratories. Group H-4 addresses acute health hazards from corrosive, toxic, and highly toxic materials. Groups H-1, H-2, and H-3 are listed in order of diminishing hazard from materials posing a physical hazard, such as fire and explosion. IBC offers five exceptions to H-Group use and occupancy based on a "list of conditions that are exempt from a high-hazard classification because of the building's construction or use; the packaging of materials, the quantity of materials, or the precautions taken to prevent fire" (IBC, 2012, Section 307).

An important table in NFPA 45 is Table 10.1.1 "Maximum Quantities of Flammable and Combustible Liquids and Liquefied Flammable Gases in Sprinklered Laboratory Units Outside of Inside Liquid Storage Areas" (NFPA 45, 2011). NFPA's Table 10.1.5 shows allowable chemical quantities for unsprinklered buildings (NFPA 45, 2011). NFPA's Table 5.1.1 provides fire separation requirements for sprinklered laboratory units (NFPA 45, 2011). NFPA recommendations are based on the number of gallons of flammable liquids stored within the laboratory unit per 100 ft^2 (28 L/m^2). The concept is that the amount of flammable liquids allowed within a laboratory unit is directly proportional to its size, up to a defined maximum area of 10,000 NASF (929 NASM). If the jurisdiction having authority adopts an edition of NFPA 5000, Building Construction and Safety Code (NFPA, 2012), and NFPA 45 as its legal building code, the project design team will use the tables referenced here to understand the allowable limits of chemical quantities in each laboratory unit. The NFPA 45 (2011) standard relies upon definitions of hazard classes for each laboratory to determine fire enclosure requirements. Laboratory units may be classified by fire hazard and by explosion hazard (NFPA 45, 2011). Class A is high, Class B is moderate, Class C is low, and Class D poses minimal fire hazard. In practice, hazard classifications of laboratory units are often made after occupancy, rather than in the planning or programming phases. This can become a serious impediment in designing flexible laboratory buildings, unless the most conservative classification is used. It can also delay obtaining an official Certificate of Occupancy from the authority having jurisdiction. Some NFPA documents are not adopted as legal code or specific sections are not referenced by the official code; project design teams must seek out the correct references to understand allowable limits for chemical storage and use. This is another example of how the design of laboratory buildings affects their operations and can potentially limit the research conducted there.

After determining the quantities and types of hazardous chemicals and materials, the project planner will investigate the distribution of these materials. Obviously, the planning process of laboratory buildings must establish a reasonable subdivision of space and use of fire protective construction assemblies to limit the spread of fire, fumes, and hazardous materials, such as highly toxic or radiation-producing chemicals, gases under high pressure, and highly pathogenic materials. The U.S. Environmental Protection Agency (EPA) establishes hazardous material classifications for chemical hazards; the Department of Transportation (DOT) determines classifications for high-pressure gases. The National Institutes of Health (NIH) in cooperation with

TABLE 1-11. Adapted from IBC (2012) Table 307.1(2), Maximum Allowable Quantity per Control Area of Hazardous Materials Posing Health Hazard

	Storage						Use Closed Systems						Use Open Systems			
	Solid Pounds[a,b]	Notes	Liquid Gallons	Notes	Gas at Cu Ft	Notes	Solid Pounds[a]	Notes	Liquid Gallons	Notes	Gas at Cu Ft	Notes	Solid Pounds[a]	Notes	Liquid Gallons	Notes
MATERIAL	(Cu Ft)		(Pounds)[a,b]		at NTP[a]		(Cu Ft)		(Pounds)[a]		at NTP[a]		(Cu Ft)		(Pounds)[a]	
Corrosive	**5,000**	a, b	**500**	a, c	**810**	b, d	**5,000**		**500**	c	**810**	b, d	**1,000**		**100**	c
Highly Toxic	**10**		**(10)**	c	**20**	e	**10**		**(10)**	f	**20**	e	**3**		**(3)**	f
Toxic	**500**		**(500)**	c	**810**	b	**500**		**(500)**	f	**810**	b	**125**		**(125)**	f

Note: 1 Cubic Foot = 0.023 Meters^3, 1 Pound = 0.454 Kilograms, 1 Gallon = 3.785 Liters.
NL = Not Limited, NA = Not Applicable, UD = Unclassified Detonable.
[a]Quantities shall be increased 100% in buildings equipped throughout with an approved automatic sprinkler system in accordance with Section 903.3.1.1. Where Note "f" also applies, the increase for both notes shall be applied accumulatively.
[b]Quantities shall be increased 100% in buildings equipped throughout with an approved automatic sprinkler system in accordance with Section 903.3.1.1. Where Note "e" also applies, the increase for both notes shall be applied accumulatively.
[c]The aggregate quantity in use and storage shall not exceed the quantity listed for storage.
[d]A single cylinder containing 150 pounds or less of anhydrous ammonia in a single control area in a nonsprinklered building shall be considered a maximum allowable quantity. Two cylinders, each containing 150 pounds or less in a single control area, shall be considered a maximum allowable quantity provided the building is equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1.
[e]Allowed only when stored in approved exhausted gas cabinets or exhausted enclosures as specified in the International Fire Code.
[f]Quantities in parentheses ( ) indicate quantity units at the head of each column.

the Centers for Disease Control and Prevention (CDC) rules on pathogenic agent classifications, among others. The current IBC (2012) lists these categories adapted in Table 1-11. The control area principle for health hazards is the same as that for physical hazards defined above. In addition, the NIH /CDC (42CFR Part 73, 2012) and the U.S. Department of Agriculture (USDA; 9CFR Part 121, 22012) generate lists of Select Agents (SA). The Department of Homeland Security (DHS) publishes the list of Chemicals of Interest (COI) (6CFR Part 27, Appendix A, 2012) and enforces regulations on both SAs and COIs, that may affect the design with respect to allowable quantities and classifications. However, the greatest impact of SA and COI designations are operational and regulatory considerations. Ideally, these health-hazard categories of materials are identified during the programming or planning phases to ensure that suitable layout, construction materials, ventilation, safety ventilation devices, and safety equipment are provided in the budget, as well as in the design of these laboratories.

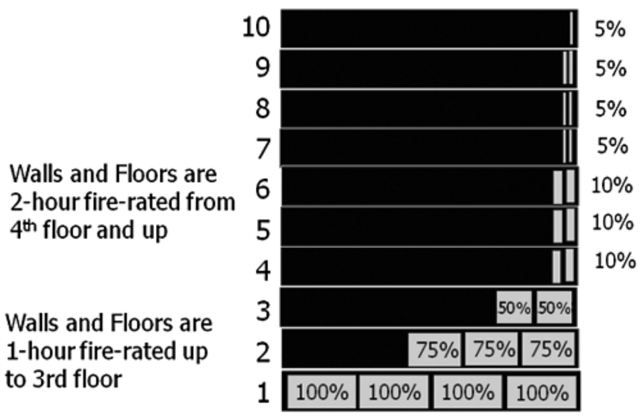

FIGURE 1-15. Section diagram of a 10-story laboratory building by floor—showing the number of fire control areas and percentage limits on chemical inventory.

1.2.5 Distribution of Mechanical Equipment and Services

Mechanical engineers, in consultation with the architects and project engineer, design the distribution of ventilation air, mechanical equipment, piped utilities, and electrical power. Plans for recommended laboratory layout options and distribution of services are presented in Figures 1-16 to 1-22. These layouts are categorized by the location at each module of the vertical shafts that contain risers of electric conduit, piped utilities, and ventilation ducts.

Vertical shafts of adequate dimensions, when located centrally or at each module, allow ducts from additional chemical fume hoods and other special exhaust systems to be installed there in the future. The same flexibility is available for piped utilities to each module through horizontal distribution on each floor and from risers located in central vertical shafts. Area needs for vertical shafts range between 1% and 10% of the net usable

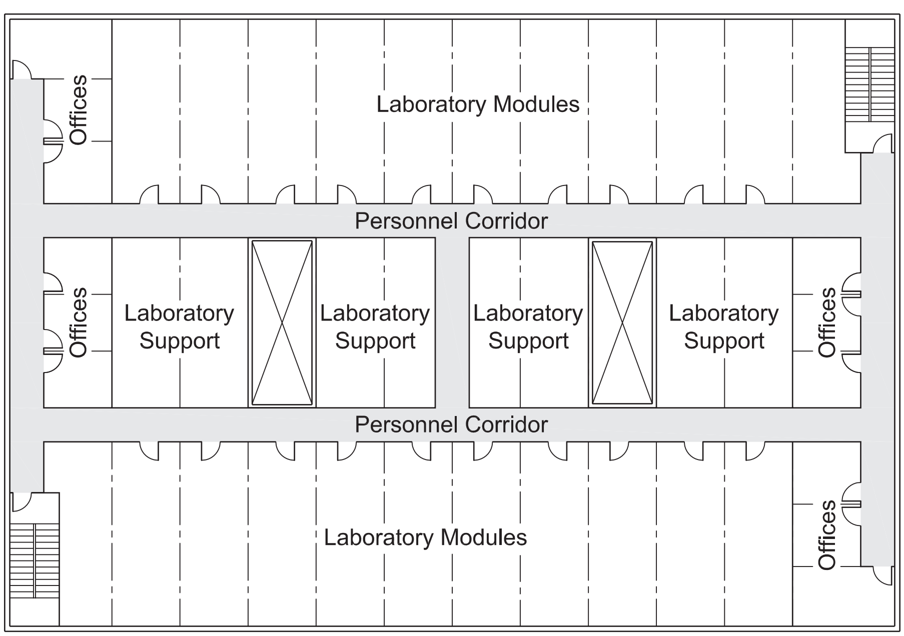

FIGURE 1-16. Mechanical, electrical, and plumbing shafts located in central core zone, building layout.

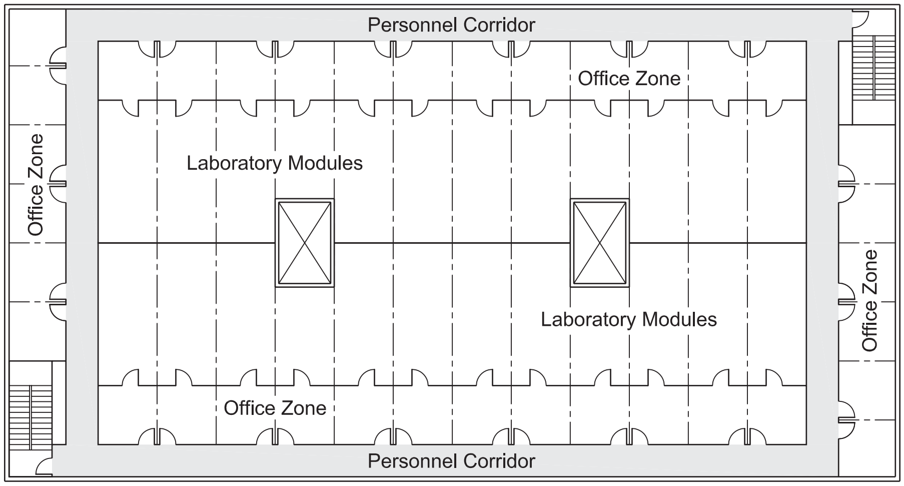

FIGURE 1-17A. Mechanical, electrical, and plumbing shafts located in center, building layout.

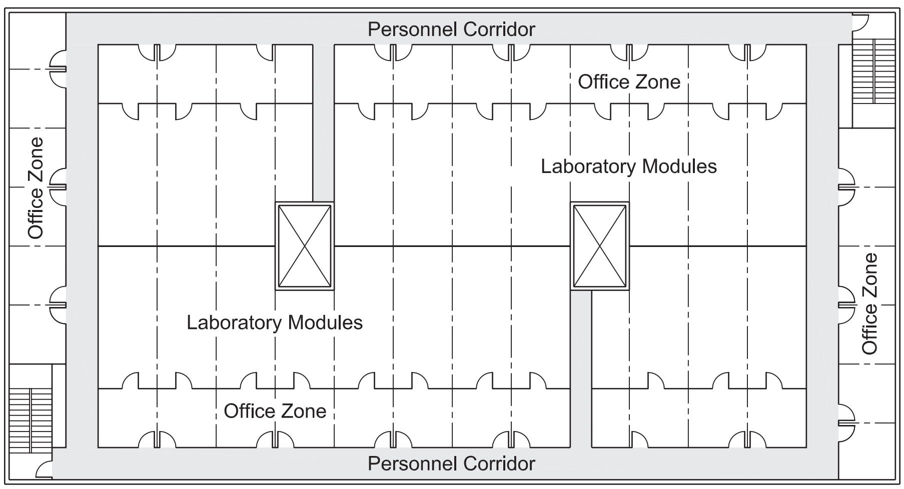

FIGURE 1-17B. Mechanical, electrical, and plumbing shafts located in center with access corridor, building layout.

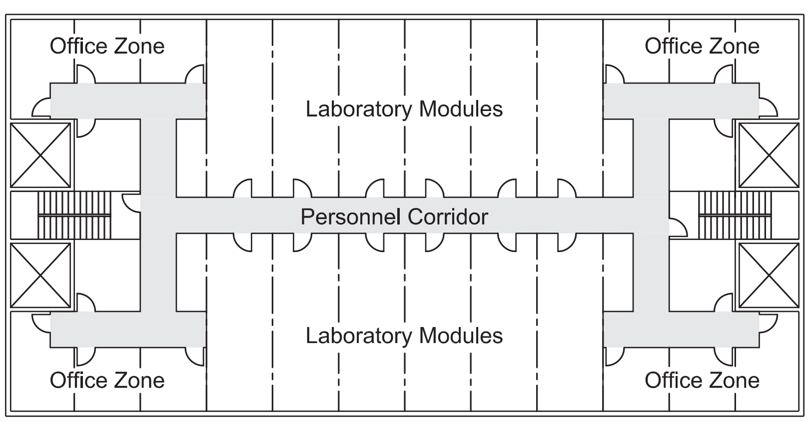

FIGURE 1-18. Mechanical, electrical, and plumbing shafts located at ends, building layout.

FIGURE 1-19A. View of interstitial floor at Fredrick Hutchinson Cancer Center Research Laboratory.

FIGURE 1-20A. View of interstitial space at Bausch and Lomb research building.

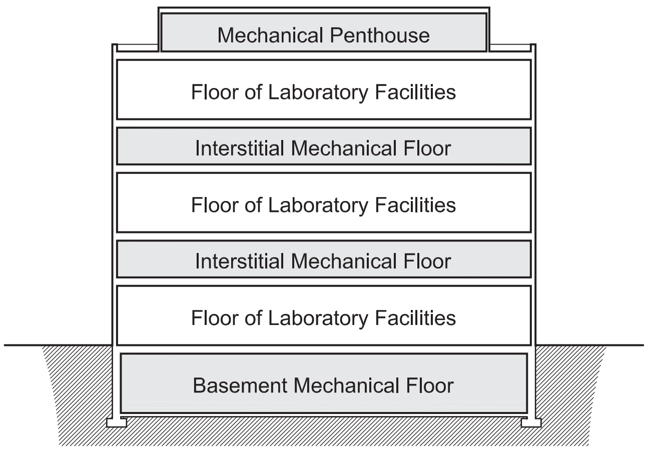

FIGURE 1-19B. Section diagram of laboratory building with interstitial floors.

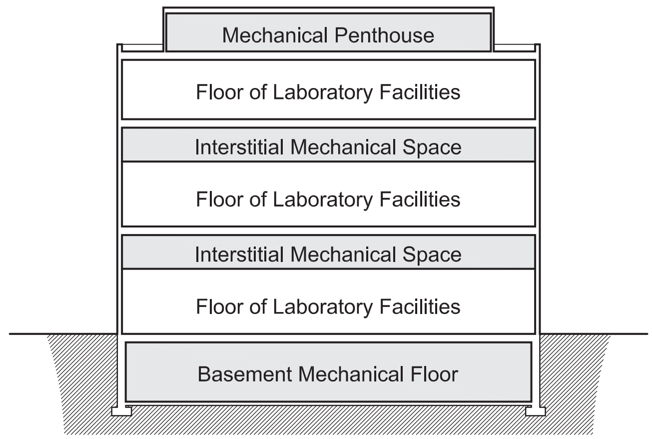

FIGURE 1-20B. Section diagram of a lab building with interstitial spaces between floors.

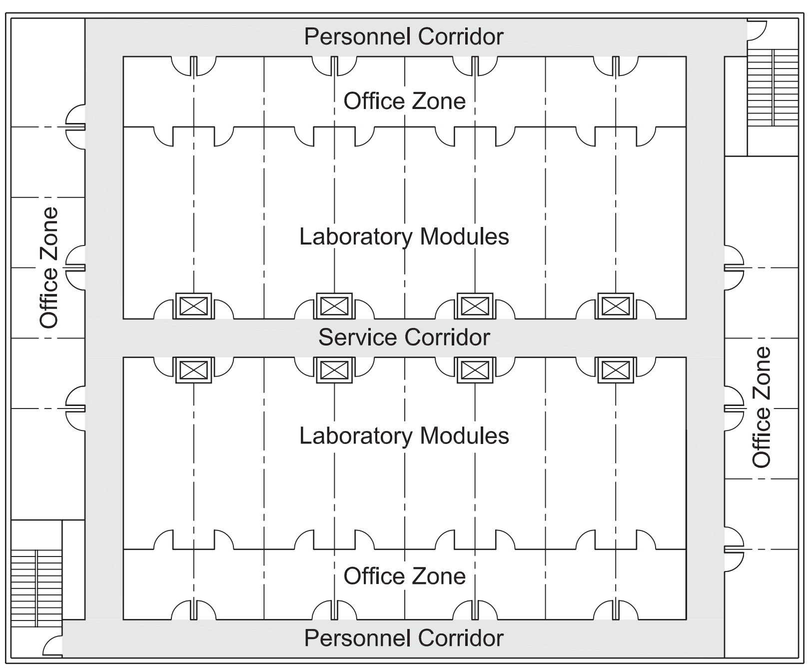

FIGURE 1-21A. Mechanical, electrical, and plumbing shafts located on service corridor, building layout.

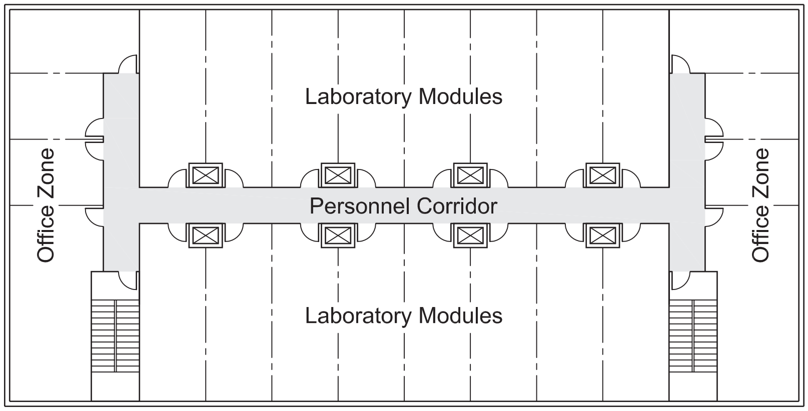

FIGURE 1-21B. Mechanical, electrical, and plumbing shafts located on personnel corridor, building layout.

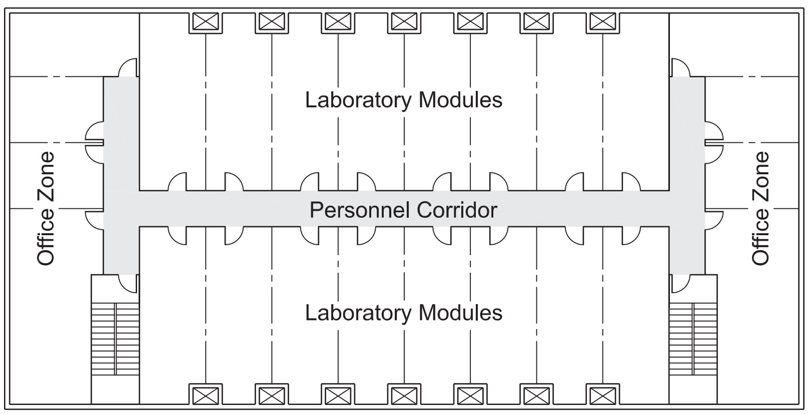

FIGURE 1-22. Mechanical, electrical, and plumbing shafts located on exterior walls of lab modules, building layout.

area on a typical laboratory floor. Engineers can locate large central riser shafts in zones that do not interfere with laboratory layouts, as illustrated in several figures here.

Adequate floor-to-floor height is needed to accommodate horizontal ducts that emerge from central shafts. Horizontal distribution on each floor still requires main exhaust duct risers to extend to the roof to discharge contaminated exhaust air in a zone well above the roof surface. Large central shafts are likely to occupy less total net area than systems designing vertical riser shafts at each module. Older laboratory buildings often do not have adequate floor-to-floor heights to allow horizontal distribution of both ventilation air and piped utilities above major corridor ceilings; Chapter 3, Sections 3.2.2.4 and 3.2.2.5 have additional information.

Laboratory buildings constructed in the 1950s to 1990s were often designed with modular vertical shafts because exhaust manifold systems for chemical fume hoods, and variable air volume (VAV) exhaust valves were not available or regarded as too risky in the laboratory design field. Chapters 33 and 34 provide descriptions of these systems. Vertical continuity from floor to floor and through the entire building to exhaust fans and other energy recovery equipment on the roof is important for both options, central vertical shafts and individual riser shafts. Otherwise, static pressure in ducts increases considerably. Chapter 33 discusses exhaust duct static pressure concepts and practice.

On the other hand, supply air systems for multistory buildings are usually provided from a combination of vertical riser and horizontal duct systems. Supply air is filtered and conditioned at air-handling units that may be located anywhere between the basement and penthouse on the roof. Primary air supply risers are also distributed in central or individual vertical shafts. From there, air is distributed to each space by horizontal ducts. Horizontal supply and exhaust air duct runs require vertical space above ceilings that is unobstructed by structural frame members to maintain comfortable and functionally adequate ceiling heights. In general, greater ceiling height beneath structural members is required for utilities and systems that require horizontal distribution. Use of interstitial floors, constructed solely for maintenance of utility and air distribution, is the ultimate example of horizontal distribution systems. The building layouts depicted in Figures 1-16 through 1-22 are discussed below.

1.2.5.1 Central Utility Shafts in Laboratory Service Core. Central utility shaft layout locates shafts within a core area on the laboratory floor (Figure 1-16) in buildings that have internal loop corridor configurations. The center core zone is for special laboratory support, building services, and vertical circulation. An advantage to laboratory building layouts with utility shafts located in a center core is improved building flexibility. These shafts can be made large enough to walk into to install new risers and make repairs, and they are accessible from corridors. Maintenance workers do not need to enter through laboratories. They are suitable for mid- and high-rise laboratory buildings. "High-rise buildings are defined as buildings with occupied floors located more than 75' (22.86 m) above the lowest level of fire department vehicle access" (IBC, 2012). Layout of the core zone can economically allow for specialized support room layouts and mechanical services because rooms in the core are closest to the utility shafts. Utility shafts located in support core areas are effective when chemical fume hoods are in a manifold system, as well as installed with dedicated risers to fans on the roof. With VAV and a fume hood, exhaust manifold systems can achieve some load diversity for supply and exhaust air volumes. Load diversity can permit reductions in duct sizes and commensurate reduction in floor area for central utility shafts. These economies are discussed in Chapters 35 and 38, Energy Conservation and Sustainable Laboratory Design, respectively.

A disadvantage in the layout shown in Figure 1-16 is that long horizontal ducts are required from chemical fume hood locations within labs around the building perimeter. These exhaust ducts then pass into central core shafts above public access corridors. Static pressure gains from length of ducts and bends lead to larger duct sizes.

1.2.5.2 Centralized Utility Shafts. Central utility shafts (Figure 1-17A) have the advantage of producing a relatively low ratio of utility shaft area to net laboratory area, improving overall building efficiency. Chemical fume hoods can be placed adjacent to shafts, or in a linear array at the rear of the laboratories. The layout of all pipes and ducts for a cluster of up to four laboratories accessible from any one of the central utility shafts permits some variation in module length than in other plans. A serious disadvantage is that access to service these shafts occurs within at least one laboratory on every floor, which is undesirable. Finger corridors to shafts, shown in Figure 1-17B, can be planned for access that does not require maintenance workers entering laboratories.

1.2.5.3 Utility Shafts at Ends of Building. End shaft arrangements work very well when supply air and exhaust air are distributed in continuous horizontal runs along both sides of the building illustrated in Figure 1-18. Air volume diminishes as the distance from end shafts increases. Reduction in air volume permits the very efficient layout of ducts. However, if cross-sectional area in ducts remains constant, these ducts provide flexibility for future additions or changes in exhaust devices and supply air volume requirements. Another advantage of end location shafts is that the laboratory floor is continuous, without major shafts interfering with laboratory layouts, adjacencies, or cores. The disadvantage is aesthetic: solid tall volumes of shafts on both building ends reduce the area available for exterior windows. Also, for very long buildings, shafts located at the ends are not as effective as centralized shafts, again due to pressure loss from the distance the ducts have to go.

1.2.5.4 Interstitial Floors. Interstitial floors are structural floors located between occupied laboratory floors: They are used by construction workers and maintenance staff to access mechanical ductwork, plumbing and fire protection pipes, electrical and IT distribution conduit and cables, and controls for all these utility systems. Interstitial floors are the best solution for maximum flexibility in laboratory buildings, which will undergo frequent renovations or modifications. Services can be maintained, modified, removed, and reconfigured without disturbing laboratories above, below, or beside the construction area. According to building codes, interstitial floors require a minimum clear ceiling height of 80 in. (2 m) for safe passage. Figure 1-19A is a photo of an interstitial floor; Figure 1-19B shows a section through an interstitial laboratory building.

All engineering disciplines should design for distribution of services in horizontal zones. For safety in the event of water infiltration or a leak, the lowest zones should be reserved for wet utilities and the highest zones reserved for electrical utilities and information technology (IT) cables.

Disadvantages are noted in Section 1.2.1.2.1, Step 9. Interstitial floors increase the building total gross area by 50% of the actual interstitial floor area. Interstitial floors require the same number of exits and exit pathways as occupied floors. There can be construction cost premiums associated with interstitial floor laboratory buildings.

Another approach to long-term flexibility in laboratory buildings is designing only interstitial space between laboratory floors. There is no structural floor, but metal frame platforms, sometimes called "catwalks," may be designed and installed for maintenance workers to gain access to limited areas, control systems, and equipment. Interstitial spaces need minimum clear ceiling heights of 80 in. (2 m) for safety, but this dimension may not be required by code. Stairs are required to provide safe egress from catwalks and access platforms. Ladders are only acceptable under certain limited circumstances to access specific equipment. The authority having jurisdiction may require two paths of egress from interstitial space platforms. Figure 1-20A is a photo of an interstitial space with a catwalk. Figure 1-20B is a section showing interstitial spaces between laboratory floors.

1.2.5.5 Individual Utility Shafts Adjacent to Service or Public Corridors. There are advantages and disadvantages to placing individual utility shafts adjacent to service corridors. Section 1.2.3.2 provides a description of service corridors; Figure 1-21A shows possible shaft locations. An important advantage is that chemical fume hoods will be located away from the door and adjacent to vertical utility shafts, favoring short, energy-efficient connections to exhaust risers. Data entry stations, which generally represent the area of lowest potential hazard in the laboratory, can then be placed at the personnel or public access corridor wall, near primary exits.

A major disadvantage of a building layout with perimeter loop corridor and a center service corridor is that laboratories are strictly interior spaces, even if light into laboratories is borrowed from public corridors on exterior walls with large windows. If laboratories are normally operated in darkened conditions, these fully interior laboratories work very well. If not, the quality of the work environment for occupants may be diminished without adequate natural light and views to the outside.

For buildings with central or internal loop corridors, where utility shafts are placed adjacent to public access corridors (Figure 1-21B), maintenance and repairs can be done from the corridor rather than from within laboratories. The second exit from the laboratory is either further along the same corridor, or through another room. In this situation, the second exit can be located away from the primary corridor exit to establish two separate paths to egress. The width of the shaft itself forms an alcove against which the laboratory door can swing outward and yet not project too far into the corridor. An expansive window area on the exterior wall is possible because it can be kept free of most utilities and mechanical services.

The primary disadvantage of locating utility shafts at interior public access corridor walls is that chemical fume hoods, which should be away from the primary egress, will also be distant from risers. Therefore, a run of horizontal duct must be used to connect chemical fume hoods, or other special exhaust devices, to the riser in the shaft. Horizontal ducts from individual chemical fume hoods are more vulnerable to corrosion from acid condensation than vertical ducts. The second disadvantage is the alternative egress route may open into another laboratory or office rather than into a corridor in a separate fire zone, as is possible in the service corridor example as shown in Figure 1-21A. A third disadvantage is that laboratory entries can occupy only the spaces between shafts. This arrangement is common in old laboratory buildings before the Americans with Disabilities Act was passed in 1991. Now, required clearances on both sides of the door latch are wider for wheelchair access. The project design team should configure spaces between individual vertical shafts with sufficient clearances, at a minimum of 5 ft (1.5 m) to meet ADA requirements.

1.2.5.6 Individual Utility Shafts at an Exterior Wall. When vertical utility shafts are located at exterior walls, chemical fume hoods can be located adjacent to shafts at the rear of the laboratory, as shown in Figure 1-22. This arrangement provides a threefold advantage: (1) There are very short horizontal runs for the duct connections to individual exhaust risers in the shaft; (2) chemical fume hoods are away from primary exits; and (3) data entry stations can be arranged at the corridor wall away from potential hazards.

Maintenance inside utility shafts must be done inside laboratories, which presents a distinct safety disadvantage for maintenance workers, as well as a major disruption to laboratory workers. Welding, as well as other repair activities that pose increased fire risks in a laboratory environment, should be scheduled when the laboratories are not occupied. A fire watch should always be maintained during welding activities in occupied laboratory buildings. Another disadvantage is that the second exit from such laboratories is likely to be near the primary exit, and open into the same public corridor. When shafts occupy most of the area of the exterior wall, window area is restricted, allowing in less natural light and views. Sustainable design principles discourage severe limitations on natural light into workplaces.

1.2.6 Structural System

The organization and dimensions of laboratory modules on a typical floor guide structural engineers on spacing of columns and sheer walls. Module gridlines may predict where dead loads from walls, benches, and equipment occur. Some structural engineers prefer to offset structural grids from module grids to avoid conflicts of major floor beams with drainpipes that can cause structural complications. There are several advantages to shifting the module grid off the structural grid by a short distance, in the range of 8 in. to 16 in. (20–41 cm), according to the structural system selected. Because sink drainpipes drop down through the floor directly beneath sinks, if the sinks are located directly above beams or a column cap, sleeves may have to be installed through these structural members. Vertical shafts for distribution of utilities and mechanical services show where major penetrations in the floor slabs will likely occur. Frequent consultations between the design structural and plumbing engineers for coordination are highly recommended so typical conflicts such as these can be resolved early in the design process. Architects must be advised of these considerations so they locate sinks and equipment drains away from structural members, where possible.

1.2.6.1 Depth of Structural Members Supporting Laboratory Floors. It is desirable to have as much space as possible above finished laboratory building ceilings (or equivalent free space when there is no finished ceiling) to use for installing the ducts, pipes, and electrical services characteristic of current laboratory facilities. Deep, solid beams reduce this unobstructed clearance, and truss-type structural members (such as bar joists) do not improve conditions significantly. During design, there is always competition between structural requirements and the needs of the mechanical trades for the ceiling space above the occupied laboratory work zones. Members of the project design team need to negotiate and strike a reasonable balance between the requirements of efficiency and economy for all construction components. In these decisions, however, project design teams must keep in mind that mechanical and electrical systems consume 30–60% of the total laboratory construction cost. Structural systems account for 10–13% of total construction cost. Ample floor-to-floor heights simplify mechanical system installation, reduce costs, and allow greater opportunities for the economies of horizontal utility distribution and future flexibility. These are compelling reasons.

1.2.6.2 Heavy Live Loads. In Section 1.2.1.2.1, Step 6, data was collected on equipment identified through an equipment inventory or the building programming process, and the spaces that pose structural or construction difficulties from heavy live loads can be determined from that data. For instance, special design and construction will be required in areas that contain equipment that is unusually heavy, or that is either sensitive to vibration or produces significant vibrations. Scientific areas or specific equipment that must be isolated from the building structure and the heavily loaded structure will have to be designed differently from areas with typical laboratory floor loads. Consideration must be given to how heavy equipment will get into the building, how it will be moved to its final location, and installed. What building areas will the extremely heavy equipment move through? Structural damage, or even failure, may occur in areas not designed for such heavy loads, even if the loading is of short duration. Heavy loads are commonly posed by radiation source equipment shielded with lead, and by large filtration tanks for central water purification systems.

1.2.6.3 Vibration Isolation Considerations. Some laboratories, such as those used for microelectronics, optical physics, surgery, neuroscience research, and electron and other high resolution microscopy suites, have very stringent requirements for structural stability and isolation from sources of building vibration. Greater than usual structural mass and stiffness, combined with building foundation stability, can contribute to reductions in structure-borne vibrations that are generated within and outside laboratory buildings by traffic, trains, and equipment. On the other hand, reduction of effects from vibration-generating factors such as airborne noise produced by high-velocity air currents within a room and within ducts, turbulent fluid flow in piping, and vibrations caused by people walking and carts moving along building corridors adjacent to sensitive areas can be handled by active vibration suppression measures and special vibration dampening and/or mounting devices.

Good site location and thoughtful building layout, particularly regarding mechanical rooms, elevators, and utility distribution pathways, can help to reduce vibration in laboratories highly sensitive to vibration. Attention to construction details of machine, duct, and pipe mountings, as well as use of local vibration-isolating devices and structurally independent platforms at sensitive equipment locations, are able to reduce effects of building vibration. Acoustical and structural engineers who are specialists in structural dynamics can analyze potential trouble spots on the site and in the laboratory building; they can establish design criteria for vibration control appropriate for the instruments and processes proposed for the building. The unit of measure commonly used for laboratory buildings by acoustical engineers is velocity in micro-inches per second (μin./s). Instruments that measure noise in decibel units (dB) and only in the audible range of humans do not provide adequate data to design structural systems. Acoustical experts can assist building designers develop strategies to reduce internally generated noise and vibration. In some laboratories and laboratory support areas, such as machine shops or glass-washing rooms, where excessive noise levels may generate a concern for health and safety, acoustical engineers should be consulted during the design phase to devise building construction methods that will isolate or reduce noise at the source.

1.2.7 Site Regulations

A new laboratory facility will be within the boundaries of one or more municipal, regional, and national jurisdictions. Each of these governing units enacts regulations governing land use and construction methods within its boundaries that will affect construction and site location of the proposed facility. Local zoning ordinances, for example, often contain criteria for the following planning concerns: fire district regulations, building use classification, building height restrictions, allowable floor area-to-site area ratio (site coverage), clearance and easements within and around site boundaries, number of parking spaces required on the site, and guidelines on the connection and use of utilities such as sewer and water. Some state regulatory and municipal agencies require permits to exhaust contaminated air from laboratory exhaust ventilation systems. Other jurisdictions having authority inspect, regulate, and issue permits for sewer discharge from laboratory buildings. When buildings are equipped with automatic sprinklers, most local zoning and building codes are less restrictive on allowable building height and total floor area. We recommend that laboratory buildings be equipped with sprinklers throughout, as discussed in Section 1.4.

Approvals by local governing boards and regulatory agencies having jurisdiction are generally required before construction can begin. Therefore, a thorough search of all applicable codes, regulations, and ordinances early in the planning phase is prudent. Early preliminary plan reviews with agencies that issue critical permits are advised because these discussions allow the owner and the project design team to anticipate problems and make adjustments to comply with local building officials' interpretation of the codes, or to appeal the building official's ruling. In addition to site requirements by jurisdictions having authority, there are many sustainable design considerations to be evaluated in developing sites for future laboratory buildings. Information on and discussion of sustainability issues and guidelines are provided in Chapter 38, Sustainable Laboratory Design.

1.2.8 Building Enclosure

The final factor that influences laboratory building layout is the building enclosure. The enclosure should provide the total building area required, comply with the building program, and meet zoning requirements. The volumetric and geometric characteristics of the structure include perimeter shape, number of floors, total building height, site coverage, and orientation to sun and prevailing winds. The concepts for sustainable design (Chapter 38) have great impact on the design of exterior building enclosures.

For renovations, building enclosure, total building area, and the structural system are known and portions of these existing systems typically are relatively fixed. Therefore, the assignment of functions to various existing spaces and proposed modifications to those spaces are conducted in a manner that will fulfill the building program goals in the most effective way. In renovation and building conversion to laboratory use, there is generally less design flexibility than in new construction. This subject is reviewed in Chapters 3 and 4 on laboratory building renovation.

1.3 GUIDING PRINCIPLES FOR BUILDING HEATING, VENTILATING, AND AIR-CONDITIONING SYSTEMS

Laboratory building ventilation is needed to provide an environment that is safe and comfortable. It is accomplished by providing controlled amounts of supply and exhaust air plus provisions for temperature, humidity, and air velocity control. Good laboratory local exhaust ventilation captures toxic contaminants at the source and transports them out of the building by means of ductwork, a fan, and sometimes an air cleaner, in a manner that will not contaminate other areas of the building by recirculation from discharge points to clean air inlets or by creating sufficient negative pressure inside the building to subject inactive hoods to downdrafts. The building supply ventilation system may provide all of the replacement air needed for local exhaust air systems in addition to taking care of all comfort requirements, or there may be a separate supply system for each function. Chapter 29, HVAC Systems, contains information on HVAC system design.

1.3.1 Laboratory and Building Pressure Relationships

Laboratory safety requires a careful balance between exhaust and supply air volumes as well as concern for the quantity of each. Even within the same laboratory type, requirements can vary depending on the hazard rating of the materials being used, the quantity of hazardous materials that will be handled, and the nature of the laboratory operations. Communication with laboratory users at an early stage in planning will help to identify and locate sites of known and potential hazards, making it possible to provide adequate facilities to meet additional needs.

Ventilation systems for laboratories can be divided into three main categories based on function.

1. *Comfort ventilation* is provided to the laboratory by a combination of supply and return airflows through ceiling and wall grilles and diffusers. The main purpose is to provide a work environment within specified temperature, air exchange, and humidity ranges. Part or all of the comfort ventilation may be provided by special systems such as fume hoods, installed for health and safety purposes.
2. *Supply air systems* provide the required replacement or makeup air removed by the health and safety local exhaust ventilation systems. Comfort ventilation air may be supplied by one system and replacement air for health and safety exhaust systems by another, or the two supply systems may be combined.
3. *Health and safety exhaust ventilation systems* remove contaminants (that cause adverse health effects, fire, or explosion or are merely a nuisance) from the work environment through specially designed hoods and duct openings.

Components of a ventilation system include fans, ducts, air cleaners, inlet and outlet grilles, sensors, and controllers. Automatic fire dampers are usually required in supply air ducts when the ducts pass through fire barriers and are advisable in any case when work with large quantities of flammables is contemplated.

1.3.2 Dedicated and Branched Air Systems

Building supply air may be provided through a central system that serves all areas, for example, offices, storage areas, and public areas as well as all laboratories. Alternatively, there may be separate systems dedicated exclusively to laboratory use. Comfort air exhaust systems (more commonly known as general exhaust systems) that serve both laboratory and nonlaboratory spaces may be, and commonly are, combined. The potential for recirculating contaminated air, particularly after a spill or accidental release, may make recirculating comfort exhaust air from laboratory spaces less attractive. However, recirculation is permissible and commonly done as long as certain conditions are met. See Chapter 2, Section 2.3 and ANSI Z9.5 (2012) and Z9.7 (2007) for more details.

Although individual dedicated exhaust ducts and fans were previously recommended for each major local exhaust hood, manifold systems that combine exhaust ducts from several hoods are more commonly used to reduce the number of small stacks on the roof or to reduce shaft space for mechanical services. Manifold systems can be considered for a renovation project where individual dedicated exhaust ducts and fans are already used only if a sound duct system of adequate capacity is already in place. The advantages and disadvantages of using manifolded exhaust duct systems versus single hood exhaust systems depend on numerous factors.

The advantages of a manifold system are

1. Lower initial cost because the number of ducts, fans, and stacks will be fewer.
2. Better atmospheric dispersion of the exhaust plume because of the enhanced momentum effect of a larger air mass exiting from the stack.
3. Less maintenance required for fewer installations.
4. Reduced duct shaft space needs within the building
5. Dilution of toxic or flammable air contaminants in exhaust streams
6. Ability to apply diversity factor. Diversity is described in more detail in Chapter 2, Section 2.3.4.6.
7. Potential for installing a redundant fan is increased.
8. Potential for installing emergency power to the fan is increased.
9. Potential for installing additional fan capacity is increased.
10. Potential for efficiently installing and utilizing VAV controls is increased.
11. Number of roof penetrations is reduced.
12. Operating costs will likely be lower.
13. Potential for locating the stack to blend in architecturally with the building is increased.
14. General exhaust can also be connected to the manifold system to allow for dilution and energy recovery.

The disadvantages of a manifold system are

1. Different exhaust streams may not be compatible. Generally, this is not a problem for common laboratory operations when the quantity of contaminants

is low and the dilution volumes in the system are high.

2. The need to add a booster fan for each individual branch that requires addition of an air-cleaning device (e.g., hoods used for radioactive isotopes) when the manifold system as a whole does not.
3. Branch ducts require careful air balancing and a control mechanism to maintain design air flow distribution (see Chapters 29, 34, and 35).
4. Inability to shut off individual components without the addition of sophisticated control systems that automatically rebalance supply and exhaust volumes for each laboratory connected to a single multi-hood exhaust system.
5. Fan failure affects all hoods in the system unless there is a back-up fan.
6. System controls (static pressure, capacity) are more complex.
7. Difficult to apply in renovation projects in existing buildings. See Chapter 3, Section 3.3.
8. Some hoods, such as perchloric acid and radiation hoods, are not recommended in manifold systems because of their specific requirements.

Before selecting a manifold system, the above advantages and disadvantages should be carefully considered for the specific applications. If a manifold system is to be used, the following requirements should be included in the design.

1. Easy access to a straight duct run in each branch to allow for air flow measurements
2. A monitor at each exhaust point to indicate correct flow
3. Easy access to all control valves for inspection and repair
4. Adequate exhaust capacity for each space served
5. Maintenance of desired directional airflow requirements for each type laboratory at all times required by laboratory type (see Part II, Chapters 5–28)
6. Negative pressure throughout manifold plenums should be reasonably uniform to maintain design airflow from branch ducts
7. A standby or cross-connected exhaust fan that can be put into service rapidly in the event of a fan failure. Alternative methods to maintain manifold suction may satisfy this requirement.
8. Emergency power to the exhaust fans
9. Training for maintenance personnel and laboratory users in the proper use, inspection, and care of manifold systems. This criterion is often overlooked and is very critical.

1.3.3 Constant Volume and Variable Air Systems

It is advisable, in all cases, to maintain constant pressure relationships between laboratory rooms (greatest negative pressure), anterooms, corridors, and offices (least negative pressure) to avoid intrusion of laboratory air into other areas of the building. The pressure cascade (step down of pressure from one level to another) will provide airflow in the desired directions. This becomes particularly important in the event of an accidental release of a volatile chemical in a laboratory. For laboratories in which hazardous chemicals and biological agents are used, pressure gradients that decrease (lower negative pressure) from areas of high hazard to areas open to public access are an essential part of the building's health and safety protective system. Even in laboratories where hazardous materials are not usually employed, animal holding rooms, animal laboratories, autopsy rooms, media preparation rooms, pathology laboratories, and similar facilities are likely to generate unpleasant odors. Graded air-pressure relationships are usually relied on to prevent release of foul-smelling air from these rooms. The reverse-pressure relationship is required for germ-free and dust-free facilities such as operating room and white room (cleanroom) laboratories. Pressure relationships are created by controlling the relative quantities of supply and exhaust air to each space. See ANSI standard Z9.5 (2012) for a more detailed discussion.

As a rule, in rooms and spaces requiring only comfort ventilation, the pressure relationships relative to the laboratory spaces are intended to be maintained constantly; this calls for invariant airflows. This does not apply to the relatively short period when opening doors to enter or exit unless required by the specific laboratory type. Health and safety ventilation systems may also be designed for continuous, invariant service. Such an arrangement is advantageous when the number of exhaust-ventilated health and safety facilities is small and when the health and safety air-supply systems have been combined with the comfort system. However, when health and safety exhaust ventilation represents the major proportion of the total air circulation requirements for the entire building, energy conservation measures call for an ability to shut down these services when they are not needed. To be effective, there must be two separate supply and exhaust air systems: (1) a comfort ventilation system that provides constant and invariant design temperature, humidity, air exchange, and room pressure conditions; and (2) one or more tempered replacement modulating air-supply ventilation system that is individually coupled to specific exhaust air devices so that both may be turned on and off simultaneously to avoid disturbing the room pressure relationships established by the comfort ventilation system. For a more thorough discussion on variable air-volume systems design, controls, and components, refer to Chapter 35. It is sometimes advantageous to provide a constant-volume system to some parts of a laboratory building and variable systems to others. The nature of the installed facilities and the intensity of laboratory usage will determine the advisability of hybrid ventilation systems.

1.3.4 Supply Ventilation for Building Heating, Ventilation, and Air-Conditioning Systems

1.3.4.1 Supply Air Volume. All air exhausted from laboratories must be replaced with supply or infiltration air. An equivalent volume of replacement or makeup air is essential to provide the necessary number of air changes needed to facilitate comfortable and safe working conditions and to maintain design pressure relationships between rooms and other spaces for health and safety protection. Overall building air pressure must be maintained positive to atmospheric pressure to reduce the rate of outside air filtration. Low internal building pressure can cause excess outside air filtration. This imbalance draws water and contaminants into the building and hastens deterioration of joint seals in the building envelope.

When laboratory health and safety exhaust ventilation requirements are not dominant, total building air-conditioning needs for maintaining heating, cooling, and ventilation loads may dictate the supply air volume to each room. Total supply air volume cannot be calculated until the amount of air to be exhausted has been determined.

A variable air-volume supply system will meet the needs of the space by reducing or increasing air quantities caused by changing space conditions and orientation. Interior spaces and those facing north will require reduced air flow, whereas those facing south, east and west will require increased air flow to meet the requirements for air-conditioning.

1.3.4.2 Supply Air Velocity, Temperature, and Discharge Location. The location and construction of room air outlets and the temperature of the air supplied are critical. High-velocity air outlets create excessive turbulence that can disrupt exhaust system performance at a hood face. In addition, comfort considerations make it necessary to reduce drafts. Therefore, the supply air grilles should be designed and located so that the air velocity at the occupant's level does not exceed 50 fpm (0.25 m/s). There is no single preferred method for the delivery of replacement air; each building or laboratory must be analyzed separately. For a more detailed discussion of location of supply air grilles, see Chapter 2.3.2.1.1, Memarzedah (1996), and the NIH design guidelines (NIH, 2011).

1.3.4.3 Air Intakes. Outside air intakes must be located so as to avoid bringing contaminated air into the building air-supply systems. Examination of likely contaminant sources, such as air exhaust stacks, should be conducted before outside air intakes are selected. The ANSI Z9.5 (2012) standard on laboratory ventilation recommends that a risk assessment of exhaust discharge location in relation to the air intake be conducted. For details, see Section 1.3.5. Experience indicates a minimum distance of 30 ft (9 m) from air-discharge openings to air intakes is recommended to reduce vapor, gas, or fume reentry problems, but it is good practice to design for the maximum feasible separation. Outside air intakes located at ground level are subject to contamination from automobile and truck fumes, whereas air intakes at roof level are subject to contamination from laboratory exhaust stacks or high stacks serving off-site facilities in the vicinity. When a building contains more than 10 stories, it is advisable to locate the air intakes at the midpoint of the building. Difficult sites such as those surrounded by elevated topography or higher buildings may require wind tunnel tests to investigate the vapor, gas, or fume reentry problem under simulated conditions. Computer-modeling programs are also available to assist in stack-discharge design and air-intake location. It is recommended that this type of study be done for all new buildings constructed as well as those undergoing major renovations.

1.3.5 Air Discharges

For all laboratory hoods, the stack on the positive side of the exhaust fan should extend at least 10 ft above the roof parapet and other prominent roof structures to minimize exposure of a worker on the roof. A minimum height of 10 ft does not guarantee that harmful contaminants will not reenter the building via the air intake.

To further assist the exhaust air to escape the roof boundary layer, the exhaust velocity should be at least 2000 fpm; there should be no weather cap or other obstructions to prevent the exhaust discharge from rising straight upward, see Figure 2-18). When selecting a laboratory stack design, consult Chapter 41 of the *2011 ASHRAE Application Handbook* (the American Society of Heating, Refrigeration, and Air-Conditioning Engineers [ASHRAE], 2011. It provides an excellent resource. Another excellent resource is Appendix 3 of ANSI standard Z9.5 (2012), which outlines a quick method for selecting laboratory exhaust system design and is reproduced in Appendix F.

1.3.5.1 Exhaust Fans. All exhaust fans should be installed on the building roof to maintain the exhaust ducts inside the building under negative pressure as a health protection measure. This arrangement makes certain that should duct leakage occur, it will be inward. In rare cases where exhaust air ductwork operates at positive pressure relative to the building interior, special care must be exercised by frequent pressure testing with the use of a tracer gas to ensure that the ductwork is airtight. Many types of exhaust fans are manufactured, but only a few meet all the requirements of a good exhaust ventilation system. Double-belted centrifugal utility-type exhaust fans are generally preferred because they are very reliable, have desirable pressure-volume characteristics, are widely available, and are easily adaptable to roof mounting and the attachment of a stack of suitable cross section and height for proper discharge of exhaust air. For critical exhaust air systems, a direct-connected fan and motor avoid failure from slackening or loss of fan drive belts. Such an installation can be further simplified by selecting a weatherproof motor and eliminating the motor and drive housing. The materials of construction for the fan, including protective coatings, should be selected to withstand corrosive and erosive conditions characteristic of the exhaust gases and aerosols that will be handled. Considerations of life expectancy and maintenance availability will influence the final selection. It is important to specify fans manufactured and rated in accordance with standards established by the Air Movement and Control Association (AMCA).

A variable air-volume exhaust fan is a necessary adjunct to a VAV supply system. It will conceptually be the catalyst that produces the signal to the supply fan that more or less air is required to maintain space-pressure relations or when a chemical fume hood is turned on or off, producing a signal of a change of status. The fan control is commonly maintained by using a static pressure controller to maintain a constant static pressure in the duct system(s). Variable air-volume systems and controls are discussed in Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment.

Fans with backwardly inclined impellors with self-limiting horsepower characteristics have been used widely for general building ventilation purposes. Fan housings are usually constructed of steel and bonderized. When used for exhaust air contaminated with low concentrations of corrosive elements, the impellor and the interior of the fan and connecting ducts are often coated with baked primers and finishes especially formulated to meet corrosion resistance standards. For severe corrosive service, especially when high humidity is also present, rigid polyvinyl chloride (PVC) or fiberglass-reinforced polyester (FRP) construction is essential. FRP is preferred because of its superior resistance to breakage and vibration cracking. It is necessary to add fire-retardant chemicals to the polyester resin. When exhaust fans are located on the roof and discharges straight upward without a rain cap, a drain connection should be placed at the bottom of the fan housing. (See Section 2.3.5.3 for additional design information.)

1.3.6 Supply Air Cleaning

All building supply air, including all portions of recirculated comfort air, should be cleaned according to the requirements of the space. The correct degree of filtration is important because excessive filtration results in a greater pressure drop through the system, thereby increasing operating costs, whereas insufficient filtration results in contamination of critical work areas or excessive maintenance costs from rapid soiling.

Many filter media are available, each providing a specified degree of air cleanliness. The choice depends on the need. Filters are classified in the *HVAC Systems and Equipment Handbook* from ASHRAE (2012, Chapter 28) as throwaway or renewable. Throwaway filters are used once and discarded. They are rated as low efficiency (35% dust removal), medium efficiency (85% dust removal), or high efficiency (95% dust removal). The performance characteristics of a number of throwaway dry media filters used for air cleaning are shown in Chapter 30, Fans. Renewable filters are seldom used for building air cleaning. Electrostatic precipitators are also used for cleaning building supply air. They are designed for 85% or 95% atmospheric dust collection efficiency. Electrostatic precipitators are always made as cleanable units, the interval between cleaning being more or less than 3 months depending on the dirtiness of the outside air. Cleaning involves washing the dust-collecting plates with detergent and water. Units may be purchased for manual or mechanical cleaning. Electrostatic precipitators generate small amounts of ozone during normal operation, and their use is counter-indicated where this gaseous compound would be considered an interference with the work to be undertaken in the new laboratories. Should this be the case, it would also be necessary to remove the same compound from the air introduced into the building because ozone regularly occurs in outdoor air in most parts of the United States. Ozone, sulfur dioxide, and most hydrocarbons that are normally present in urban air can be removed from ventilation air by passing it through gas-adsorption activated carbon beds after particle filtration or after treatment by electrostatic precipitators.

Cleaning of recycled comfort ventilation air before discharge to the atmosphere is seldom, if ever attempted, nor is it necessary. This is not always true for health and safety system exhaust air. Filtration, liquid scrubbing, and gas adsorption may be needed to prevent the emission of toxic, infectious, and malodorous gases and aerosols to the atmosphere. Exhaust air cleaning is discussed in Section 2.3.5.3 and Chapter 31, Air Cleaning.

1.3.7 Supply and Exhaust Ducts

All ductwork should be fabricated and installed in accordance with Sheet Metal and Air-Conditioning Contractors' National Association's standards (SMACNA, 2010). Ducts should be straight, be smooth inside, and have neatly finished joints. All ducts must be securely anchored to the building structure. The usual material for supply and exhaust ducts in comfort ventilation systems is galvanized steel. More corrosion-resistant materials, such as stainless steel, FRP, and PVC, are frequently used for health and safety system exhaust ducts. See Chapter 33, Table 33-1 for information on the chemical resistance of materials used for exhaust ducts and plenums. It should be noted that the NFPA standard requires a building to have sprinklers where PVC duct is used for exhaust ducting (NFPA 45, 2011).

It is essential that all ducts be constructed and installed in a leak-tight manner if the system is to function as the designer intended it to. This is especially important for exhaust ventilation ducts, which usually operated under far higher negative pressures than do comfort ventilation systems; hence, the leakage through even small gaps in longitudinal seams and joints leads to a significant drop in system efficiency. The seams and joints of stainless steel ducts are usually welded airtight. Plastic pipes are constructed without longitudinal seams, and the joints are sealed with plastic cements of appropriate composition. Inorganic sealants should be used for some hoods such as perchloric acid hoods. It is easier to construct airtight systems with round ducts than rectangular ducts. Rectangular ducts should be avoided at any cost in the health and safety exhaust air systems because they cannot be made airtight by any practical method. For noncorrosive material-containing systems, seams and joints may be sealed with long-lasting ventilation duct tape. Whatever method is selected, it is essential that ducts be made leak-tight if they are to give satisfactory service.

Ideally in a constant-volume ventilation system engineering and installation can be accomplished to ensure appropriate air supply and exhaust from laboratories without use of any "trimming dampers" in all duct runs. In reality, these dampers are frequently used. The designers routinely provide capacity for growth or changes in use and the air quality is adjusted to meet design requirements. The "trimming dampers" also known as balancing dampers are sometimes a necessity but should be avoided whenever possible. In a variable volume system where per design requirements the volume needs to modulate, special terminal boxes are provided. More details are provided in Chapter 29, HVAC Systems.

Ducts are excellent conductors of sound. Care must be expended to secure them so as to avoid vibration and the propagation of noise. In addition, they should be isolated from fans and other noise-generating equipment with the use of vibration-reducing connections and the installation of acoustical traps in the ducts between noise and vibration sources and the point of discharge to occupied areas.

1.3.8 HVAC Control Systems

Controllers are essential to ensure that all HVAC systems in a laboratory building will operate in a safe and economical manner. Control systems are needed for temperature, humidity, air exchange, and pressure regulation.

Control systems can be electric, computer-based, or pneumatic. Pneumatic systems are operated by high pressure. The source of the air should be different from that of the laboratory air because the loss of control air can have a significant effect on building systems. Variable air volume systems require unique control systems such as static pressure controllers, inlet vane dampers on centrifugal fans, feather blades on vane axial fans, variable speed drives, and solid-state rectifiers. Variable air-volume systems and controls are discussed in Chapter 34.

1.3.8.1 Temperature Control. The temperature in most laboratory buildings does not require close regulation—that is, no better than ±3°F (±1.75°C). Worker efficiency and productivity may be affected adversely when ambient temperature control permits temperatures to exceed 85°F (30°C) in summer or to fall below 60° F (16°C) in winter.

The comfort range is determined by combining dry bulb temperature, relative humidity (RH), and air velocity to derive a value called *effective temperature* (ASHRAE, 2009). An effective temperature of 77°F (25°C) is considered to be a very desirable condition. This is achieved in winter by 68°F (20°C) with 35% RH (65%), and in summer by 78°F (26°C) with 50% RH (65%). More information on comfort indexes and comfort standards is given in Chapter 29.

1.3.8.2 Humidity Control. Although close humidity control is not required in most laboratory buildings, some degree of humidity control should be included to provide comfort and avoid extremes. Some laboratories such as animal facilities and microelectronic laboratories have specific, tight humidity requirements. Refer to the type of laboratory in Part II. Chapter 29 should be consulted for additional details on humidification systems.

1.3.9 Air Exchange Rates

Recommended air exchange rates for comfort ventilation for public areas and for commercial and industrial workplaces are contained in the ANSI/ASHRAE ventilation Standard 62 (ANSI/ASHRAE, 2010). In most organized communities, the applicable building code will prescribe minimum ventilation rates for indoor air quality for a variety of building users. They are the lowest air exhaust rates that must be maintained in each occupied room, even when the health and safety exhaust ventilation systems are turned off. See Chapter 2, Section 2.3.4.1 for a discussion of air exchange rates required in laboratories.

In crowded areas where smoking is permitted, the minimum air exchange rates required by the building codes will be inadequate to please a high percentage of nonsmokers; in addition, outside air rates of 30–60 CFM per active smoker will be needed to keep tobacco smoke concentrations close to background levels (ANSI/ASHRAE 62-1, Ventilation for Acceptable Air Quality; ASHRAE, (2010).

1.3.10 Fan Rooms (Equipment Rooms, Mechanical Rooms)

Because of the nature of the work that is required to maintain the equipment within the fan room, the design of the room is important from the standpoint of ensuring the owner of delivering a complete system that performs as designed and that will continue to perform during the life of the building. All too often, the space provided for a fan room is too small to accommodate the equipment that is required to provide the services to the building. Nevertheless, the mechanical contractor viewing the mechanical drawings installs the equipment that is required to provide the building services. The equipment is usually installed double-tiered or in a fashion that makes it easiest for the sheet metal contractor because ducts are in locations that dictate the fan location. The piping contractor, not having the necessary room, installs the piping in the easiest manner. The control contractor, being the last in, and of course having the smallest pipe, can install equipment and piping with ease. Often these contractors are not concerned with the need to maintain the equipment, to make it accessible for changing a motor, bearings, filters, and all other maintenance that may be required over its useful life. It is extremely difficult when you open the door and find the following situation: There is no space; it is difficult to stand up in many locations, or identify the equipment because it is not visible. Sometimes, it is almost impossible to get to it.

The layout of the fan room should be considered as important as the rest of the building, with input from those responsible for maintaining the building. Easy access to all equipment and controls are required.

1.3.11 Glass-Washing Rooms

Glass-washing rooms are a part of a laboratory facility for a department or several departments all using the same facility in a laboratory building to perform the necessary washing and sanitizing of glassware used in research.

The glass-washing facility requires large amounts of hot water, which is usually generated in the facility or remotely located close to the facility because of intermittent use. Most laboratories require that the glassware be washed, sterilized, and ready for use the following morning, or the washing and sterilization is done early in the morning so that the glassware is ready for use in experiments that day.

The normal procedure is to wash the glassware in hot water and provide either distilled or purified water for the final rinse to provide exceptionally clean glassware and remove all traces of residue from previous experiments. This requires exceptionally large amounts of thermostat-controlled hot water, and the method of heating is usually steam. It also requires an adequate source of pure water that is used as the final rinse.

Adequately sized drain piping should be provided to remove the volume of water that is discharged to drain, usually by a butterfly valve that is normally a part of the glassware washer.

Because of the high heat load in the glass-washing area, the need for cool air is required year round so that those involved in this practice can perform their work in relative comfort. Autoclave rooms are also in this category, and the comfort of the operators should be considered.

Cage-washing areas also require large amounts of hot water delivered over short periods; therefore, equipment sizing is critical to ensure capacity is available when needed. Linear trench drains are often installed at exit doors of rack washers to capture drips from clean cage racks as they are removed from washers. Other very large floor drains are needed in all areas of cage-wash facilities.

1.3.12 Commissioning

Commissioning is a term used for final acceptance of mechanical/electrical systems in the building. The process is fully described in Chapter 36, Project Execution and Bidding Procedures, and Chapter 37, Commissioning.

1.4 GUIDING CONCEPTS FOR LABORATORY BUILDING LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

It is the purpose of this book to help design laboratory buildings that provide work space and buildings that are free from the risk of accidental injury or loss to its users and visitors, the building or equipment and materials contained therein, and to preserve and protect the environment. This section provides important information, sometimes overlooked, regarding 10 building and material safety systems that are not discussed elsewhere in the book, but relate to the accomplishment of the book's purpose. Each of these issues will need to be reviewed when planning or designing each laboratory building or any areas within the building in conjunction with any necessary risk analysis. Where the risk is deemed higher than acceptable, implementation of the concept will become mandatory to eliminate the risk. The use of health and safety professionals to provide help in such decisions is advised.

1.4.1 Emergency Electrical Considerations

The primary electric feed to laboratory buildings should be as reliable as possible. For example, separate and distinct feeds connected to a common bus and then to two separate transformers with network protectors should be installed, and each transformer should be large enough to carry the building load so that the loss of any one line will not interrupt building power. When such practice is not possible, some other fail-safe electrical connection designs should be used. Even with this type of reliable service, it is often necessary to provide emergency electrical power because any of the primary electrical service components (transformers, main feeders, etc.) may fail and then emergency power will be required. Each building should have its own emergency power source that is adequate for all egress lighting and other life-safety requirements, as defined in the National Electrical Code (NFPA 70, 2011), and if adopted by the jurisdiction having authority, Safety to Life from Fire in Buildings and Structures (NFPA 101, 2012). Several critical systems in laboratories may have to be connected to emergency electrical power for continuity of operation as well as for safety concerns. Items that should be connected to emergency electrical power are the following:

1. Fire alarm systems
2. Emergency communication systems
3. Fire pump, when it is electrically driven and not backed up by another driver
4. Emergency smoke evacuation systems
5. One elevator for buildings over 70 ft in height
6. Egress pathway lighting
7. Emergency lighting in rooms
8. Egress signs that require lighting
9. Exhaust fans connected to critical health and safety exhaust ventilation systems
10. Makeup air systems serving critical exhaust systems
11. Heating systems and controls to prevent the building from freezing during temperature extremes
12. All other systems whose continuing function is necessary for safe operation of the building or facilities during an emergency period

Certain experimental procedures may need to be protected against power failure due to the critical nature of the experimentation, research, or process. Loss of power may result in costly loss of data, experimental animals, materials, and research time. Determination of which procedures qualify for connection to the emergency power is usually an administrative issue. The design team should try to determine through communications with building owners and users what the most likely maximum emergency power electrical load may be.

In general, diesel-driven generators are preferred because they are readily available, easily maintainable, and easy to start (in less than the 10 s mandated by NFPA 70, 2011). Gas turbines are available in smaller sizes and may be satisfactory. However, turbine starting is sometimes difficult for large-size generators.

The emergency generator should be connected to the selected load with a series of transfer switches. The transfer switches should automatically turn over to emergency power when normal power fails. Annunciation through a local or remote panel should be provided to let operators of the building know which transfer switch has changed modes. The generator control board should have an ammeter installed so that operators can see the load on the generator and manually select other loads when necessary.

If emergency electrical power distribution is run throughout the facility, it must be run on a distribution system that is separate and distinct from the primary electrical distribution system. This is to prevent concurrent cable failure of both primary and emergency power in case of a fire or other emergency condition. Some building codes require construction of separate electrical closets because emergency power distribution panels cannot be in the same closet.

1.4.1.1 Uninterruptible Power Supplies. Many laboratories use uninterruptible power supplies (UPSs) for computers and other critical electronic equipment. These devices produce normal line voltage (120 vac, 60 Hz) when the normal power for the area has failed, and they represent a serious electrical shock hazard to unsuspecting emergency responders. When these devices are applied and managed individually, central control becomes very difficult. Therefore, consideration should be given to installing a central UPS with adequate current capacity to handle all the equipment in the laboratories and associated offices. It would then be easy to have the UPS current switched off for safety when necessary. Central UPS systems frequently employ battery systems that require no hydrogen gas ventilation considerations. In situations where older type lead acid batteries are banked together to provide high-capacity electrical energy, the storage rooms or facilities containing them must have passive ventilation and explosion-proof electrical fixtures.

1.4.2 Construction Materials

According to the International Building Code (IBC, 2012), laboratory buildings engaged in education, research, clinical medicine, and other forms of experimentation are included in the category of Class A building construction and Use Group B. Therefore, all pertinent sections of the IBC code should be followed in the design and construction of all laboratory facilities, with special emphasis on fire safety for unusual as well as all ordinary hazardous conditions. Specifically, the provisions of Article IX (Fire-Resistive Construction Requirements) that govern the design and use of materials and methods of construction necessary to provide fire resistance and flame resistance must be followed. Flame resistance is defined in the code as "the property of materials, or combinations of component materials, which restricts the spread of flame as determined by the flame-resistance tests specified in the code." Some of the specific subjects covered in Article IX of the IBC are enclosure walls, firewalls and firewall openings, vertical shafts and hoist ways, beams and girders, columns, trusses, fire doors, fire windows and shutters, wired glass, fire-resistance requirements for plaster, interior finish and trim, and roof structures. The purpose of the requirements of the IBC code is to provide a building that will allow its occupants to safely exit from the building in case of fire and unusual smoke conditions.

The general philosophy of all interior building design with respect to the combustible properties of construction materials should embrace the idea of eliminating those materials responsible for rapid flame spread and heavy smoke generation. Materials used in research buildings provide more than ordinary cause for concern because the sources of fire initiation in laboratories are many times more numerous than for most other building uses.

1.4.3 Safety Control Systems for Laboratory Experiments

Provisions should be made for automatic or remote shutdown of well-defined portions of a building's services that provide energy to experimental operations having the capability to threaten parts of the building or personnel within the building or to produce undesired effects should the experiment get out of control while attended or unattended. This type of control should be used for the most sensitive types of operations where uncontrolled failure could result in a major loss of equipment or damage to the building, the release of highly toxic substances into the environment, or personal injury. A study committee composed of designers, users, and health and safety professions should determine areas of risk that will benefit by application of laboratory experiment safety control systems (see Section 1.4.5.2). In addition to the safety control aspects of remote data processing, there may be a need for the laboratory user to transfer data electronically to remote locations such as an office or central computer facility. Data transfer cables with RS 232 and other standard connections are routinely installed in modern laboratory facilities.

1.4.4 Fire Detection, Alarm, and Suppression Systems

Costs of retrofitting fire alarm, detection, and suppression systems after the construction of any type of laboratory building are very high. Therefore, consideration should be given to these systems during the design stage of new and renovated laboratories. Automatic water sprinklers are considered the best fire control for laboratory buildings.

1.4.4.1 Fire and Smoke Detection. Laboratory buildings should be equipped throughout with a heat-sensitive fire detection system as a minimum. A standard sprinkler system will qualify, even with its inherently slower detection ability. Another way of providing good building detection coverage is with the use of linear temperature sensing (LTS), also known as line-type systems. These are basically temperature sensing wires and they detect completely along their run, but have the capacity of providing specific information about the location of any detected spot. They are faster to respond to an elevated temperature area and provide a much earlier warning of the existence of a fire than the water sprinkler system can. These LTS systems can also be used in laboratory units and therefore integrate the complete building detection system.

There are other types of detection systems that can be deployed in the laboratory building and its' rooms. They include but are not limited to

- Optical flame detection (OFD)
- Aspirating smoke detection (ASD)
- Rate of rise thermal detection (ROR)
- Ionization products of combustion detection (ID)
- Optical smoke detection (OSD)
- New developments such as video image flame detection (see NFPA 72, 2013)

There continues to be advancement in the technology of flame, heat, smoke, and products of combustion detectors. For example, for several years ID detectors were the fastest devices used to detect insipient fires. That distinction now goes to OSD and ASD detectors. This becomes important when the risk to the building and its' contents demands rapid detection. The employ of a qualified fire protection engineer to assist in the up-to-date selection of detection and suppression systems is recommended.

- Optical flame detectors work by sensing infrared radiation at specific flicker rates. They are good in situations where flames break out quickly, as with flammable liquids and gases.
- Aspirating smoke detection systems work by drawing room air through a tube into a central analyzing box where lasers or other devices look for the small particles of smoke. The ASD systems are presently the fastest responding type, but are rather expensive.
- Rate of rise thermal detectors work by having air, trapped in a small chamber, which when heated, expands against a diaphragm, and triggers a switch. They are inexpensive, but not well suited for early detection; however, they are reliable.
- Ionization detectors work by having room atmosphere pass through a chamber in which an ionized beam becomes attenuated by collisions with smoke or other particles of specific size, triggering an electrical signal.
- Optical smoke detectors work by scattering light from light-emitting diodes (LED) off the smoke particles passing through the system chamber. The scattered light triggers the signal. These detectors have become fast, reliable, and relatively inexpensive.

The use of LTS and OSD systems for general building detection is recommended. Where different detection systems are more appropriate for specific laboratory and other building room applications, they are discussed in the respective chapters in this book. Fire and smoke detectors must meet Underwriters Laboratory (UL) standards and be installed and spaced in accordance with National Fire Alarm Code (NFPA 72, 2013).

1.4.4.2 Fire Suppression.

1.4.4.2.1 Fixed Automatic Systems. All laboratory buildings should be designed with a complete water sprinkler system in accordance with "Installation of Sprinkler Systems" (NFPA 13, 2013). Wherever unusual hazards exist, special design of the system will be necessary. When water is contraindicated for fire suppression because large amounts of water-reactive materials such as elemental sodium are present, or large amounts of flammable or combustible liquids are used or stored, other complete fire suppression systems must be used. The specific application of these nonsprinkler systems are discussed in the appropriate chapters on laboratory type.

There are several fire suppression systems available today and more are constantly being developed. Freon, also known as Halon is no longer available due to its negative environmental impact. At the present time, a mixed gas system composed of nitrogen, argon, and carbon dioxide is recommended. This system extinguishes fires by reducing the oxygen content below that which will support a flame, yet this atmosphere has been determined to be safe for humans. It was developed by Tyco Fire Products (www.tyco-fire.com) and carries their registered trademark name of INERGEN®.

Another important fixed automatic extinguishing agent is aqueous film-forming foam (AFFF). AFFF extinguishes fire by smothering it from getting combustion air. This system can be used in some locations where water sprinklers would not be advised due to the problems created by water run-off. One of those locations is within the laboratory building and is the fuel containment room for a liquid-fueled, such as a diesel fueled, emergency electrical generator. Most building codes require that this fuel containment room be separate from the generator room. A fire involving the diesel fuel would be floated on top of sprinkler water run-off and possibly carried to other rooms or areas. Another appropriate system for this fuel location is one of the dry chemicals such as sodium or potassium bicarbonate or mono-ammonium phosphate. They extinguish flammable and combustible liquid fires through chemical reaction with the flame along with some smothering. The AFFF system is recommended due to its effectiveness. In some instances, a water-spray, also known as a water-mist system may be effective.

Due to the complexities of design, application and installation requirements of these engineered or preengineered off-the-shelf systems, a licensed or certified fire protection or safety engineer should participate in decisions regarding the best suppression system to use in any given application. All automatic fire suppression systems should be connected to the building central alarm system.

The vertical standpipes used for the water sprinkler system should also serve fire-hose cabinets on each floor of the laboratory building. Hoses should have a 1.5-in. (3.8 cm) diameter, and vertical risers should be so spaced that the maximum length of hose to reach a fire will not exceed 50 ft (15 m). Longer hose runs may lead to loss of fire control because a hose length exceeding 50 ft (15 m) is difficult for persons lacking adequate hands-on fire training to turn on and use.

1.4.4.2.2 Hand-Portable Extinguishers. In the last several years, several new extinguishing agents have been developed for hand portable use along with the more familiar water, carbon dioxide, and several types of dry chemicals. Some of these were developed to replace ozone-depleting chlorofluorocarbons (CFC) such as Halon 1211, but many still contain some ozone-depleting chemicals. It is believed that these agents will eventually become obsolete as better materials are developed. There are basically four types of hand-portable fire extinguishers for general use. They are

- Gas, such as carbon dioxide compressed in heavy steel cylinders
- Water in pressurized fiberglass and metal containers
- Dry chemicals in pressurized metal containers
- Vaporizing liquids (new) using hexafluoropropane in pressurized metal containers

Gas and vaporizing liquid extinguishers are considered "clean" agents in that they leave no messy residue (an important criteria when convincing a lab person to use one). Dry chemicals and water, as expected, leave a mess behind after use. From an effectiveness standpoint, the hexafluoropropane (FE 36, developed by E.I. DuPont Inc., Wilmington, DE) is the best and is recommended for use within laboratory rooms and other specific areas discussed later. Dry chemical is the next best extinguishing agent; the most diverse agent is mono-ammonium phosphate in that it will extinguish all three classes of fires—normal combustibles, flammable and combustible liquids, and electrical fires. Gas and vaporizing liquid extinguishers are recommended for general use throughout the building, in halls, corridors, and egress ways. In most instances, hand-portable fire extinguishers are used to assist with exiting from the room or building. There are instances where personnel will return to a laboratory room that is on fire, for the purpose of extracting notes and materials or to fight the fire itself. This activity is not advised, but because it does take place, it is recommended that fire extinguishers installed in halls and exit ways be sized large whereas units in laboratory rooms may be smaller. 6A 60BC is the minimum size recommended for halls and corridors. All fire extinguishers must be sized and installed in accordance with NFPA 10 (2010), "Portable Fire Extinguishers."

Special portable fire extinguishers should be considered for unique situations, e.g., areas where quantities of reactive and pyrophoric metals are in use or storage. Special portable fire extinguishers use suppression agents other than those listed above.

1.4.5 Alarm Systems

1.4.5.1 Fire Alarms. A Class A supervised fire alarm or signaling system should be installed throughout the laboratory building in accordance with "Installation, Maintenance and Use of Protective Signaling Systems" (NFPA 72, 2013). All manual pull stations, sprinkler alarms, and heat-sensing detectors should be connected to it. Pull station placement should be in accordance with NFPA 101 (2012) and should not be placed more than 200 ft (60 m) apart. All other detection systems should alarm locally, and connection to the Class A system should be considered only after reviewing the false alarm potential. Alarms should be detectable by in both sight and sound.

1.4.5.2 Laboratory Experiment Alarms. Provisions should be made for a three-tier alarm system in all laboratories in which experiments or operations need to be monitored for failure. The system should be designed to provide a communications link between the laboratory and a central station in the building that is monitored at all times, or at the very least, when there are unattended operations in laboratory units. In general, a three-tier alarm system consists of the following parts:

1. A local alarm for room occupants that is audible and visual.
2. An audible and visual alarm outside the laboratory door to pinpoint the location of the problem.
3. Remote annunciation to a constantly attended location.

The use of remote annunciation is critical in a large facility because it may be the only means of alerting service personnel to the problem. Remote annunciation is most critical during weekends and normally unoccupied periods. It is strongly recommended that alarms to all electromechanical equipment connected to laboratory safety systems be annunciated to a central location.

Microchip technology is in use in many highly hazardous laboratories and may be advantageous when more than one kind of alarm condition must be monitored, for example, fire, hazardous gas, and HVAC system alarms. The single monitor for observing all three of the examples is advantageous to having three different systems to observe.

1.4.5.3 Other Service Alarms. Alarms may be needed to indicate failure of exhaust fans and makeup air systems as well as for fire, loss of pressure, loss of temperature, presence of toxic gases, low air oxygen content, and other conditions that often require monitoring. In addition, whenever building services that are not normally monitored could cause loss through flood, fire, explosion, or release of hazardous materials in the event of their failure, a separate monitoring system with three-tier alarms should be installed.

1.4.6 Hazardous Waste

A designated area must be provided to collect, consolidate, and store hazardous chemical, biological, and radioactive wastes in preparation for disposal. Hazardous chemical waste can be stored for short periods in the laboratory unit before being collected and sent to a central holding room or being shipped off site for disposal. For the laboratory unit, space for this temporary storage needs to be added to the floor plan and for the laboratory building, a more sophisticated facility may be necessary. General waste collections, such as those from janitors' operations, should consist solely of paper, glass, and other nonhazardous and recyclable refuse; waste chemicals should never be included. General waste and recyclable materials should be collected and stored in an area of the building not associated with the chemical, biological, and radioactive waste storage areas. The waste storage facility should be within the main laboratory building or in an external facility. (See also Chapter 27 for more information about hazardous laboratory waste management.)

1.4.7 Chemical Storage

In addition to provision for the storage of a few days' supply of chemicals in each laboratory unit, there should be a central chemical storage room for bulk supplies. This room should be sized to hold enough materials to ensure continued operations without interruption. The purchasing (procurement) department can assist in determining what this quantity should be. "Just-in-time" (JIT) purchasing agreements with suppliers, where advantageous, can reduce the necessary size of the central chemical storage room. Compressed gas cylinders should not be stored in the central storage room unless there is a separate room within it with high rates of ventilation. Good floor drainage should also be provided for compressed gas storage areas, where floor water may be present.

See Chapter 28 for more detailed information on chemical storage rooms.

1.4.8 Compressed Gas Storage and Piping

When the laboratory management elects to pipe gases from a central compressed gas-dispensing facility instead of placing cylinders in each laboratory unit, or where both methods are used jointly, the location of the central facility, and an outline of the design features must be included as an integral part of the building design.

A central gas cylinder farm should be located in a room with an outside wall for explosion venting in the ratio of 1 ft^2 (0.09 m^2) of venting surface for each 40–60 ft^3 (3.7–5.6 m^2) of room volume (see "Venting of Deflagrations," NFPA 68, 2007) or be housed in a room attached to the outside of the building. The room should be adequate in size to store in segregated locations full cylinders and empty cylinders awaiting removal for refilling as well as the manifolds necessary for piping the gases. Ventilation in this room should be adequate to vent heat from the sun load on the roof and walls and to remove gases leaking from a failed regulator or valve. Air changes should be a minimum of six per hour for flammable gases as required by OSHA 1910.106 (OSHA, 2013).

Rigid and secure supports for gas tanks should be provided; they should be designed to provide storage flexibility. Compressed gas cylinders for a high-pressure laboratory should be located within that laboratory, or close to it, to avoid any loss of high discharge pressure in the piping system that occurs for the general laboratory gases when piped from a central location.

The gas piping system should be of stainless steel with low-pressure reducers and orifice restrictions wherever the pipe diameter exceeds 1/4 in. (6.4 mm) to limit accidental flow into any area. The piping system should be external to the building when this is feasible. Internal piping and exterior piping alike should be exposed to view wherever possible. Excess flow check valves may also be installed to control runaway flow conditions of toxic or flammable gases. Double-walled gas piping should be considered for highly toxic and flammable gases such as arsine and hydrogen, which are used in microelectronics. (See "Cleanrooms," NFPA 318, 2012; "Standard for the, Storage, Use and Handling of Compressed and Liquefied Gases in Portable Cylinders," NFPA 55, 2010; and Chapter 23, Microelectronics and Cleanroom Laboratories.)

1.4.9 Fuel Gas

A fuel gas shutoff must be provided for the entire building and should be located so that it is easy to reach and activate under emergency conditions. Shut-off valves should be provided for individual laboratories, groups of laboratories, or specific laboratory floors. For more information on this requirement, see Section 4 of Chapter 2.

1.4.10 Hazardous Materials, Equipment, and Procedure Signs

Personnel within a laboratory building or about to enter a laboratory building need information regarding the operations, materials, risks, or special situations within. This information is most important to emergency response personnel, such as firefighters and police or ambulance personnel, so they can carry out their functions safely and efficiently, usually in a time of stress. Many communities and cities have ordinances requiring certain signs such as those for flammable storage, which must be complied with. An acceptable system of signs is described in "Standard System for the Identification of the Hazards of Materials for Emergency Response" (NFPA 704, 2012). It was developed around nonlaboratory users of chemicals, but in some cities and communities there may be an ordinance that requires compliance with NFPA 704 for laboratories. When a specific code is not mandated, we recommend the adoption of a less complicated and less difficult to interpret sign system that can better protect emergency response personnel in laboratory situations, such as the system shown in Appendix C.

1.4.11 Fire Command Room

Many city fire departments require that laboratory buildings be equipped with a Fire Command Room that is directly accessible by the fire department via a locked outside door and within which are the fire detection and alarm electrical panels along with existing floor plans of the building, MSDSs, and a computerized building data system.

1.5 MISCELLANEOUS SERVICES

1.5.1 Lighting

Good lighting is essential in a laboratory due to the often long hours spent by researchers in performing highly detailed and concentrated work. The lighting energy intensity may also be significantly higher than other spaces, i.e., office space. Lighting energy impact on a building is not as large as other usage, for example, as compared to HVAC systems, but it is significant. Local energy codes and ASHRAE standard 90.1 impose limitations with the intent is to promote an energy conservation discipline to minimize overlighting and overuse of electrical power. "Energy Efficient Design of New Buildings" (ASHRAE Standard 90.1, 2010) and "Energy Conservation in Existing Buildings–Commercial" (ASHRAE Standard 100, 2006) should be consulted.

The Environmental Protection Agency's (EPA) Labs21® project has done significant research on laboratory lighting and recommend:

1. The use of lighting to supplement daylight
2. The use of direct–indirect ambient lighting parallel to benches
3. The use of task lighting wherever possible and reduce overall ambient lighting

Lighting is also affected by the brightness of walls, ceilings, floor, and work surfaces. To aid in the proper distribution of light a white or nearly white ceiling is recommended. Floors have more to do with contrast reduction in the visual field than with contributing to the overall lighting quality.

1.5.2 Lighting Level Guide

Suggested minimum lighting densities are presented in Tables 1-12 and 1-13. Two terms are defined: lighting power density (LPD) in watts/ft^2 and room cavity ratio (RCR).

The RCR is a shape factor (e.g., for a room) used in lighting calculations.

TABLE 1-12. Lighting Power Densities Using the Building Area Method. (Adapted from ASHRAE 90.1, 2010)

Building Area Type[15]	LPD (W/ft^2)
Automotive facility	0.82
Convention center	1.08
Dining: bar lounge/leisure	0.99
Dining: cafeteria/fast food	0.90
Dining: family	0.89
Exercise center	0.88
Fire station	0.71
Gymnasium	1.00
Health-care clinic	0.87
Hospital	1.21
Library	1.18
Manufacturing facility	1.11
Museum	1.06
Office	0.90
Retail	1.40
School/university	0.99
Transportation	0.77
Warehouse	0.66
Workshop	1.20

TABLE 1-13. Lighting Power Densities Using the Step-by-Step Space Method

Common Space Types[a]	LPD, W/ft^2	RCR Threshold
Atrium		
First 40 ft in height	0.03 per ft (height)	NA
Height above 40 ft	0.02 per ft (height)	NA
Audience/Seating Area—Permanent		
For auditorium	0.79	6
For Performing Arts Theater	2.43	8
For Motion Picture Theater	1.14	4
Classroom/Lecture/Training	1.24	4
Conference/Meeting/Multipurpose	1.23	6
Corridor/Transition	0.66	Width < 8 ft
Dining Area	0.65	4
For Bar Lounge/Leisure Dining	1.31	4
For Family Dining	0.89	4
Dressing/Fitting Room for Performing Arts Theater	0.40	6
Electrical/Mechanical	0.95	6
Food Preparation	0.99	6
Laboratory		6
For Classrooms	1.28	6
For Medical/Industrial Research	1.81	6
Lobby	0.90	4
For Elevator	0.64	6
For Performing Arts Theater	2.00	6
For Motion Picture Theater	0.52	4
Locker Room	0.75	6
Lounge/Recreation	0.73	4
Office		
Enclosed	1.11	8
Open Plan	0.98	4
Restrooms	0.98	8
Sales Area	1.68	6
Stairway	0.69	10
Storage	0.63	6
Workshop	1.59	6

(*Continued*)

TABLE 1-13. (*Continued*)

Building-Specific Space Types	LPD, W/ft^2	RCR Threshold
Automotive		
Service/Repair	0.67	4
Bank/Office		
Banking Activity Area	1.38	6
Convention Center		
Audience Seating	0.82	4
Exhibit Space	1.45	4
Courthouse/Police Station/Penitentiary		
Courtroom	1.72	6
Confinement Cells	1.10	6
Judges' Chambers	1.17	8
Penitentiary Audience Seating	0.43	4
Penitentiary Classroom	1.34	4
Penitentiary Dining	1.07	6
Dormitory		
Living Quarters	0.38	8
Fire Stations		
Engine Room	0.56	4
Sleeping Quarters	0.25	6
Gymnasium/Fitness Center		
Fitness Area	0.72	4
Gymnasium Audience Seating	0.43	6
Playing Area	1.20	4
Hospital		
Corridor/Transition	0.89	Width < 8 ft
Emergency	2.26	6
Exam/Treatment	1.66	8
Laundry/Washing	0.60	4
Lounge/Recreation	1.07	6
Medical Supply	1.27	6
Nursery	0.88	6
Nurse's Station	0.87	6
Operating Room	1.89	6
Patient Room	0.62	6
Pharmacy	1.14	6
Physical Therapy	0.91	6
Radiology/Imaging	1.32	6
Recovery	1.15	6
Hotel/Highway Lodging		
Hotel Dining	0.82	4
Hotel Guest Rooms	1.11	6
Hotel Lobby	1.06	4
Highway Loding Dining	0.88	4
Highway Lodging Guest Rooms	0.75	6
Library		
Card File and Cataloging	0.72	4
Reading Area	0.93	4
Stacks	1.71	4
Manufacturing		
Corridor/Transition	0.41	Width < 8 ft
Detailed Manufacturing	1.29	4
Equipment Room	0.95	6
Extra High Bay (>50 ft Floor to Ceiling Height)	1.05	4
High Bay (25-50 ft Floor to Ceiling Height)	1.23	4
Low Bay (<25 ft Floor to Ceiling Height)	1.19	4

TABLE 1-13. (*Continued*)

Building-Specific Space Types	LPD, W/ft^2	RCR Threshold
Museum		
General Exhibition	1.05	6
Restoration	1.02	6
Parking Garage		
Garage Area	0.19	4
Post Office		
Sorting Area	0.94	4
Religious Building		
Audience Seating	1.53	4
Fellowship Hall	0.64	4
Worship Pulpit, Choir	1.53	4
Retail		
Dressing/Fitting Room	0.87	8
Mall Concourse	1.10	4
Sales Area	1.68	6
Sports Arena		
Audience Seating	0.43	4
Court Sports Arena—Class 4	0.72	4
Court Sports Arena—Class 3	1.20	4
Court Sports Arena—Class 2	1.92	4
Court Sports Arena—Class 1	3.01	4
Ring Sports Arena	2.68	4
Transportation		
Air/Train/Bus—Baggage Area	0.76	4
Airport—Concourse	0.36	4
Audience Seating	0.54	4
Terminal—Ticket Counter	1.08	4
Warehouse		
Fine Material Storage	0.95	6
Medium/Bulky Material Storage	0.58	4

[a]In cases where both a common space type and a building-specific type are listed, the building specific space type shall apply.

$$RCR = 5H\,(L + W) / L \times W$$

or alternatively,

$$RCR = (2.5)\ \text{Total Wall Area} / \text{Floor Area}$$

where H = height, L = length, and W = width of the room. A cubical room will have an RCR of 10; the flatter the room the lower the RCR.

The illumination levels in the *IESNA Lighting Handbook* (Illuminating Engineering Society of North America [IESNA], 2000; http://www.iesna.org/) for laboratories that are very high. Therefore, designers have a challenge to understand from the users what their needs are.

1.5.2.1 Corridor and Egress Lighting

Researchers often work alone and late at night. Properly lit corridors and stairways give a feeling of security to users. It is important that lighting designers provide this feature. Many times egress lighting is connected to emergency power to ensure sufficient lighting in the case of a power outage.

1.5.3 Plumbing

1.5.3.1 Sinks. Sinks should be constructed of materials such as stainless steel or epoxy resins that are resistant to chemical and other spillage. The drain should have a removable, cleanable strainer to prevent solid materials from getting into the drainage system.

1.5.3.2 Liquid Wastes. Most local plumbing codes now require certain types of acid-resistant waste piping for many kinds of laboratory drains.

Many municipal wastewater authorities also impose strict controls on the nature and quantity of chemicals that may be discharged into the sewers. Local authorities having jurisdiction should be consulted. For example, in the Boston area the local Massachusetts Water Regulatory Authority (MWRA) limits the mercury discharge level to 1 part per billion (ppb). In certain cases, on-site filtration and treatment may be both advisable and cost effective.

A comprehensive program of contaminant control that includes source reduction, infrastructure cleaning, and end-of-pipe treatment should be considered during the early design phases. Source reduction is a preferable strategy because it tends to eliminate the problem. Internal cleaning capability should be provided by installing accessible traps and sampling stations. The nature and size of end-of-pipe treatment will depend only on the presence of one or more contaminants that needs to be removed.

A central pH control system may not be present in many older facilities and should be installed where required by local codes. This consists of a collection tank where acids and caustic liquids can be introduced to maintain pH level before discharge.

Many municipal waste/sewer authorities require that laboratory waste volume be measured and continuously monitored for pH. When the wastewater is not clear, many conventional water measuring devices and systems are unsuitable. Weir-type meters have been used successfully for waste measurement.

Another alternative is collection and containment of only the most hazardous fraction of the liquid waste to lighten purification requirements for the bulk of the liquid waste stream. Collected wastes may need to be treated as regulated hazardous waste.

1.5.3.3 Water Pressure. Sufficient water pressure should be available for all building needs. Separate piping loops are necessary for the sprinkler system and for potable water; the latter category includes drinking fountains, emergency eyewash fountains, deluge showers, lavatory sinks, and water closet water. Anti-scalding temperature-regulating devices should be installed in service hot water supply lines. For deluge shower and eyewash specifications, see Appendixes A and B. For standpipes in locations where municipal water supply does not provide sufficient pressure, separate water pressure booster systems are necessary. In locations where municipal water supply is not present or where the quantity or quality is not adequate, separate water storage systems will be necessary. For example, a laboratory building being built in desert regions may require a complete self-contained water system.

1.5.3.4 Drinking Water Protection. Laboratory buildings need to protect their drinking water systems from contamination. This requires separation of the laboratory water system within the building from the water systems used for drinking, kitchens, toilet rooms, emergency showers, and eyewashes. For example, the need to conserve and protect entire municipal drinking water supplies from contamination due to back siphonage or backpressure is addressed by the Massachusetts Department of Environmental Protection (DEP) Regulation 310 CMR 22.22 (CMR, 1990), which describes the need and the approved method for protecting state, city, town, and local drinking water systems from any possible degradation caused by cross contamination. A double-check valve, reduced-pressure backflow preventer with a relief valve and open drain is the only method approved by the regulation. It offers the best available backflow protection and can be used on toxic and non-toxic systems.

Testing of backflow prevention equipment is required semiannually in Massachusetts. An additional reduced-pressure backflow preventer installed in a bypass arrangement is required to enable these tests to be done without loss of water service to the building.

The drinking water system inside the building should be protected in the same way as the municipal supply, by using reduced-pressure, backflow preventers, and a bypass line to avoid loss of service during semiannual testing. The hot water supply system requires similar treatment to provide the same kind of protection to building occupants.

1.5.3.5 Water Harvesting and Reuse. Sustainable design may require water harvesting on-site, which will need on-site storage. Contamination control measures must be taken in this situation as well.

The reuse of wastewater is an excellent strategy and must be carefully reviewed and adopted wherever possible. Two examples are as follows:

1. Reject water created in the production of "clean water" is high-quality water and can be used for a variety of purposes.
2. Gray water from washbasins in the bathrooms can be reused for toile t flushing. Design must be done carefully, and storage and a separate piping system for toilets need to be installed. However, the savings can be significant.

1.5.4 Support Services

When designing laboratory buildings it is important to consider the health and safety issues related to laboratory support service personnel, e.g., maintenance, housekeeping, and security. Adequate space must be provided for housing these people and their equipment. These areas should be provided with the same health and safety features as the other laboratory areas, including adequate ventilation, fire protection, lighting, and emergency egress. In addition, there may be some special considerations. For example, nonslip floor surfaces should be provided in glass-washing rooms, janitor closets, and similar areas in which floors are frequently wet. Adequate general ventilation and work space must be provided in mechanical and fan rooms. Provision must also be made for routine maintenance of laboratory ventilation systems, and adequate access must be provided.

1.5.4.1 Security. Depending on the nature of the laboratory and the work being carried out, several issues of security may need special consideration. Granting agencies and organizations often have unique stipulations. Most of these issues require attention in the planning stage as they involve such considerations as cable installation during the construction phase and the allocation of space. A central or main security office may be necessary, which would include TV monitors providing real-time monitoring of the premises via remote cameras. Guard stations at entrances to the building may be required; unguarded entrances may have to be wired to prevent unauthorized opening. Special locked rooms and areas may need to be monitored because they contain materials ranging from chemicals and drugs to proprietary systems and records.

Some laboratories make extensive use of magnetic-stripe ID cards in place of guard stations. Many laboratories have guards located at stations during normal working hours and switch to card-operated entrances during off-hours. Some use has been made of card-operated turnstiles, which can produce serious bottlenecks during evacuation emergencies. Biometric-type systems that use fingerprint or retina scans are becoming more common.

1.5.5 Electrical Harmonic Currents

Engineers have long been aware of the potential problems in building electrical systems caused by harmonic currents, but these problems were less noticeable before the extensive use of computers and other electronic devices.

A systems report published by Atkinson, Koven, Feinberg Engineers (Atkinson, 1991) provides a good description of the problem. Electrical systems found in most buildings are designed for traditional linear loads. Linear loads (such as motors, electric heaters, incandescent lighting, and fluorescent lighting with standard wire-wound ballasts) consume current on a continuous (linear) sinusoidal basis. When this type of load is balanced across a typical three-phase, four-wire power source, the return currents of each phase cancel each other out in the neutral conductor and there is no risk of transformer overload or wires overheating.

Now, however, because of the proliferation of solid-state devices (e.g., data processing units, personal computers, variable-speed motor drives, and electronic ballasts), nonlinear electrical loads result in the creation of harmonic currents in the distribution system. This is because solid-state devices draw current in pulses. The frequency of the pulses and their waveshapes are classified in terms of the harmonics of the fundamental frequency (60 Hz). Generally, the pulses appear in the third, fifth, and seventh harmonics (180, 300, and 420 Hz). The third harmonic current is the predominant contributor to the overall system current waveform distortion. The fifth and seventh harmonics have a lesser impact. These third harmonic currents do not cancel in the neutral conductor. The neutral conductor can be subject to extremely high currents (even in excess of the phase lag currents), causing hazards such as transformer overload and overheating of neutral wires and bus bars. This situation can place an excessive amount of stress on the electrical power systems, causing equipment failure and/or reduction in the system's life expectancy.

To offset these problems,

1. Install special electronic filters or transformers
2. Oversize the common neutral in a three-phase, four-wire circuit
3. Add a separate neutral conductor from each branch circuit to the electric panel

In an upgrade of an existing electrical system, a qualified electrical engineer using a harmonic analyzer should be retained to evaluate the extent of the problem and recommend any solutions.

1.5.6 Steam Quality

Steam is often used in laboratory buildings for heating, humidification, sterilization, and glass- and cage-washing activities.

The steam quality and its content could become a concern and should be evaluated. Steam quality is defined thermodynamically. A 100% steam quality is saturated steam. Steam of lesser quality contains moisture droplets.

Steam additives are mostly boiler treatment compounds and are added in the steam system to prolong the life of the boiler tubes, piping, and other auxiliary systems. These chemicals raise pH. They may possess some toxic properties. The most common compounds used in boiler treatment are amines, namely, morpholine, cyclohexylamine, and diethylaminethanol (DEAE). These amines minimize the effect of dissolved gases such as carbon dioxide and sulfur dioxide on metals in boilers, feed water heater, and piping.

Poor steam quality sometimes leaves residue condensate on items being sterilized. This condensate could consist of a concentration of steam additives that may cause operational problems. For example, if animal feeds are being sterilized with poor-quality steam, such steam condensation would contaminate the feeds.

For humidification, direct steam injection remains a very popular method. However, when steam contains components that could cause health problems, a case can be made that such steam additives should not be used in direct-steam injection-type humidification systems. Several steam-to-steam generator systems are available in which building steam can be used as a heat source to evaporate city water (or in some cases, deionized [DI] water) to make "clean" steam. Other cold-mist humidification systems are also available that do not depend on steam at all.

Careful study of the steam additives proposed and of building steam should be done. A study done by Battelle Institute on their own steam ("Determination of Amines in Indoor Air from Steam Humidification"; Edgerton, 1989) provides a good discussion.

The Battelle study concluded that concentration of amines measured in indoor room air during normal operation of the boiler and humidifier can be very low compared with any established health standards. On the other hand, a NIOSH case study by Hills, Lushniak, and Sinks (1990) showed that overtreatment of boilers with such water treatment compounds can cause a health hazard for the occupants. Studies by Fannick, Lipscomb, and McManus for NIOSH (1983) show the effects of such compounds in a museum and report associated problems. Other NIOSH reports (McManus and Baker, 1981) provide a good background. The workplace amine concentration will depend on the boiler treatment compound control systems. If excessive chemicals can be introduced, this could result in problems.

At this time, the use of control steam for humidification should not be prohibited. Careful review of the current literature on boiler systems is needed before a final decision can be made. This work was validated by Memarzadeh (2009) of the National Institutes of Health in a White Paper called "Use of Clean Steam vs Utility Steam." He summarized the issues as follows (p. 7):

> "The way in which corrosion inhibitors are added to boiler systems may affect the risk of toxic exposure. Volatizing amines should only be used in systems with well-maintained automatic dosing devices. Manual dosing should not be allowed when automatic dosing equipment is inoperable. Individuals who design and maintain corrosion inhibitor feed mechanisms should be aware of the consequences of chemical overfeed. Time averaged estimates can be derived from historical weather data, boiler plant records, and simple titration measurements of steam condensate concentration from the holding tank. Care must be taken to avoid loss of the amine additive through volatilization when using titration methods to determine condensate concentration. The material balance may be used for real time modeling if the appropriate variables are constantly monitored and the effect of internal removal is known.
>
> With careful monitoring of water chemistry, along with periodic direct testing for amine levels in the humidified air space, operators of steam humidification systems can be assured that room air amine levels will be well below the permissible levels that may cause adverse effects in humans. Facility engineers and managers should consult a qualified water treatment professional to arrange for an evaluation of their steam humidification system, including possible airborne amine testing."

1.5.7 Pure Water System

Pure water is required in various research activities. The purity measurement is specific resistance in ohm/centimeters (Ω/cm) and is expressed in conductivity (μΩ at 77°F/25°C). Purity of water used for pharmaceutical laboratories, for example, is defined by United States Pharmacopoeia USP NF (2012).

The *Handbook of Facilities Planning* (Ruys, 1990) provides a good description of various other types of pure water standards. Standards have been established by the National Committee for Clinical Laboratory Standards (NCCLS), the College of American Pathologists (CAP), the United States Pharmacopoeia (USP), the American Society for Testing and Materials (ASTM), and the American Chemical Society (ACS). (See Table 1-14)

1.5.7.1 Production Methods. There are several methods for producing pure water. The most common are

- *Deionization.* Impurities are removed by passing water through synthetic resin beds with affinity for dissolved ionized salts and gases. The process will

TABLE 1-14. Pure Water Classification

Classification	Resistivity (MΩ/cm)
Absolute purity	18.3
Ultrapure	1.0
High purity	1.0
Low purity	1.0
Biopure	Pathogen free, sterile .1 ppm total dissolved solids

not remove bacteria, pathogens, particulates, or dissolved organic compounds. This process can provide water of 15–18 MΩ/cm purity. Resin beds require regeneration with sulfuric acid and caustic.

- *Distillation.* Impurities are removed from water by converting the liquid to vapor phase and then recondensing it as distilled water. Distilled water is free of all pathogens except dissolved ionized gases. Distillation can provide water of 0.8–1.0 MΩ/cm purity if the feedwater has been pretreated.
- *Reverse osmosis.* Impurities are removed by utilizing hydraulic pressure to force pure water through a membrane. This process removes some pathogens. It will not remove dissolved ionized gases. It is good for water with high total dissolved solids (TDS).
- *Filtration.* Solid particulate impurities are removed by passing the water through a porous membrane or medium. Types include sand filters, diatomaceous earth, cartridge filters, etc.
- *Other systems.* Combinations of the four systems described above may be used; in certain cases, special processes may be employed.

1.5.7.2 Pure Water Piping. Pure water is very aggressive and corrosive. The impurities in the pipe material in contact with the water can leach out into the pure water. The end-product water then may be unacceptable to the user. Common pure water piping materials are aluminum (type 3003), glass, polyethylene, polypropylene, stainless steel, and tin-lined copper. The cost of the material, joining methodology, pipe hanging detail, and most important, the possible water contamination described above must be considered before making the final selection.

A recirculated system provides the best assurance of an ongoing clean system. Dead legs in piping systems should be avoided because they could be a source of bacterial growth.

1.5.7.3 Central Pure Water Supply versus Onsite System. In a small project, an onsite system will be most cost effective. In a large building, it is sometimes not cost effective to produce and pipe the highest grade of pure water throughout the building. A reasonable grade, centrally produced, and "polished" locally in specific laboratories to obtain the final quality, may be more cost effective.

1.5.8 Pest Control

Pest control and IPM (Integrated Pest Management) should be considered in all phases of design, construction, and commissioning for any new or renovated building. There are many design features that will minimize or eliminate pest issues and the need for pesticide use once the building is in operation. Some that should be implemented in the various phases are as follows:

Design Phase

- Require door sweeps on all exterior doors.
- Require appropriate dumpster location, water sources, and floor drains for proper housekeeping practices.
- Provide access panels to "dead spaces" (pipe chases, ceilings other than drop ceilings).
- Require sealed hatches or coverings for ejector pits.
- Require bug lights in mechanical spaces that are likely to be wet.
- Exterior ledges, particularly over entrances, should be eliminated or anti-bird/pigeon measures (e.g., netting) considered.
- Exterior fencing around play areas or park-like settings should have 24″ metal extension below grade to prevent rodent burrowing.
- Exterior building envelop should be tight and flush with no gaps larger than 1/8″ to prevent pest access (bees, ants, mice, rats, roaches, etc.).
- Food-service counters, benches, cabinets, etc., should be flush with floors and walls to prevent nesting opportunities underneath and behind.
- Tree wells and raised beds with masonry features should be screened, grated, or meshed to prevent harborage and nesting areas.
- Require door sweeps on all interior mechanical space, food service, loading dock, and other operational doors.
- Require overhead rolling doors to be flush and tight with no gaps larger than 1/8″.
- Require overhead doors to be motion-detection capable to automatically close when no activity is present.
- Waste containers (dumpsters/compactors), particularly animal bedding and food-service compactors, should be watertight and sealed between the rim and container to prevent food sources from leaking.
- Floor-mounted heating and cooling vents should be screened to 1/4″.
- Custodial closet and storage space floors should be finished and door sweeps required.
- Trash/recycling rooms should have floor drains and a water source for proper housekeeping procedures.
- Exterior landscaping features should be kept a minimum of 4″ off the exterior of the building.

- Exterior plantings should be species that rodents and pests do not like and are not attracted to (trees and shrubs that produce berries or nuts, have root systems conducive to burrowing, etc.).
- Sidewalks and parking lots should slope and drain during inclement weather to prevent puddling.

Construction Phase

- Construction project management company or selected contractor should be required to contract a pest-control provider during the construction phase to better coordinate IPM efforts.
- Work site should remain "broom clean" and all waste generated removed daily, particularly food waste generated from coffee/lunch breaks, to prevent harborage and food sources.
- A pest-control survey and clean out should occur prior to the interior of the building being "buttoned up."
- Appropriate rodent control actions must be taken along the perimeter and surrounding areas of the construction site.
- Exterior doors to the job site should be kept closed at all times, particularly before/after deliveries, to prevent access for pests.
- Pest-control inspections of the job site should occur regularly, a written report generated, and corrective actions taken. Penalties should exist to ensure compliance.
- Construction dumpsters need to be emptied on a regular basis and the dumpster location site kept clean to prevent harborage and food sources.
- Exterior and site trash receptacles should be required for use by construction personnel and catering trucks.
- Pest sightings or evidence of pest activity should be immediately reported to Project Management and pest-control vendor for immediate action.

Commissioning Phase

- Prior to the project being turned over to the owner, the project should be inspected and certified as being "pest free." If not, remedial action should take place and the project is not officially handed over until it is deemed pest free.

For Renovations

- Neighbors of the area to be renovated should be notified of the potential for increased pest activity due to the renovations nearby and instructed on how and what they should do regarding pest activity.
- Access points from the perimeter of the project area to neighboring spaces should be sealed and door sweeps installed as much as possible.
- Doors leading to and from the renovation area should be kept closed at all times, particularly exterior doors.
- Debris dumpsters should be emptied as quickly as possible.
- Staging areas should be required to be "broom clean" at all times to prevent harborage and food sources.
- Exterior doors to the job site should be kept closed at all times, particularly before/after deliveries, to prevent access for pests.
- Construction dumpsters need to be emptied on a regular basis and the dumpster location site kept clean to prevent harborage and food sources.