edcetera | Architects

The Basics of the Design of University Labs

Course Number: AIAPDH244
2 LU|HSW

PO Box 449 Pewaukee, WI 53072 (888) 564-9098

arch-support@edcet.com

University Lab Design Final Exam

1. If you have two standard sinks and one cup sink in a teaching lab, how many sinks need to be accessible?
   a. 1
   b. 2
   c. 3
   d. None of them

2. Which type of countertop is the least expensive?
   a. Epoxy resin
   b. Phenolic resin
   c. Chemical resistant plastic laminate
   d. Stainless steel

3. What type of exhaust should be specified for soldering stations?
   a. Snorkels
   b. Fume hoods
   c. Biological safety cabinets
   d. Gloveboxes

4. What is a control area?
   a. The area in a building that contains the controls for the building's security system
   b. Spaces within a building where quantities of hazardous materials NOT exceeding the maximum allowable quantities per controls area are stored, dispensed, used, or handled
   c. The area at the physical plant where engineers adjust the Building Automation System controls
   d. Spaces within a building where quantities of hazardous materials exceed the maximum allowable quantities per controls area are stored, dispensed, used, or handled.

5. What determines the class of a chemical?
   a. The flashpoint
   b. The type (flammable or combustible) of chemical
   c. The flashpoint and type (flammable or combustible) of chemical
   d. The quantity in which it is deemed hazardous

6. Which of the following can be located in a high-traffic area?
   a. -80 freezer
   b. Gas cylinders
   c. Non-recessed safety showers
   d. AED

7. Which of the following labs is the costliest? (Assume everything about them is the same except the factors listed below.)
    a. A dry lab with fixed, wood casework
    b. A wet lab with fixed, steel casework
    c. A wet lab with mobile, wood casework
    d. A wet lab with mobile, steel casework

8. Which of the following equipment is sensitive to vibration?
    a. Microscopes
    b. Balances
    c. Lasers
    d. All of the above

9. With COVID, the distribution and return of ____ has changed at some universities.
    a. PPE
    b. Chemicals
    c. Glassware
    d. Hand sanitizer

10. Which of the following is false regarding control areas in buildings?
    a. The control area can be a single lab.
    b. The control area can be a group of labs.
    c. Non-lab rooms cannot be within a control area.
    d. Control areas are required to be separated from other areas with fire-rated separations.

11. If a flammable hazardous material has a flash point of 70°F and a boiling point of 102°F, how would it be classified?
    a. Class IA
    b. Class IB
    c. Class IC
    d. None of the above

12. How many control areas are allowed on the second floor of a building?
    a. 1
    b. 2
    c. 3
    d. 4

13. What percent of worksurfaces in a teaching lab must be accessible?
    a. 5
    b. 25
    c. The Accessibility Standards do not specify a percentage. A 30-inch length of worksurface must be accessible.
    d. The Accessibility Standards do not specify a percentage. A 36-inch length of worksurface must be accessible.

14. Which of the following is required in a BSL1 lab?
    a. Self-closing doors
    b. Available autoclave
    c. Eye wash
    d. Protected vacuum lines

15. Which of the following is required in a BSL3 lab?
    a. Impervious surfaces
    b. Self-closing doors
    c. Negative airflow into laboratory
    d. All of the above

16. If a P.I. is doing research utilizing an agent that may have lethal consequences, what BSL rating should the rating of the lab be?
    a. BSL1
    b. BSL2
    c. BSL3
    d. BSL2 or BSL3

17. Which of the following is not typically seen on college campuses?
    a. BSL1
    b. BSL2
    c. BSL3
    d. BSL4

18. Which of the following statements is true?
    a. Teaching labs are more likely to have mobile casework over fixed casework.
    b. Teaching labs require more airflow during unoccupied times than during occupied times.
    c. Research labs are more likely to have mobile casework over fixed casework.
    d. Size of mechanical components cannot be reduced in a research lab due to the fume hoods not needing to run concurrently.

19. Which of the following is likely to be found in a dry lab?
    a. Electronics
    b. Wood casework
    c. Recirculated air
    d. All of the above

20. Which of the following is likely to be found in a wet lab.
    a. Chemicals
    b. Fume hoods
    c. Piped gases
    d. All of the above

The Basics of the Design of University Labs

Course description
This course will introduce you to academic/university lab design. It will cover the basics for designing teaching and research labs as well as the buildings dedicated to such.

Learning objectives
Upon completion of this course, you should be able to

1. Identify how to program academic and research labs and the buildings that house them.
2. Understand design considerations for production, effectiveness, and safety for various lab types.
3. Recognize the layout of functional labs that enhance learning while focusing on regulatory requirements and safety.
4. Examine current lab design trends for safe, efficient, and productive use.

Part 1: PROGRAMMING

Paul Rand said, 'The designer does not begin with some preconceived idea. Rather, the idea is the result of careful study and observation, and the design a product of that idea.'

What exactly is programming? If you are in the design field, you already know that it is 'a process leading to the statement of an architectural problem and the requirements to be met in offering a solution.' (Pena, W & Parshall, Steven, 2001, p. 14) It is the gathering of information. You are gathering the pieces of a jigsaw puzzle, so you can put it together in the form of a design. You are also analyzing those pieces. Maybe some pieces do not fit anywhere in the puzzle; you toss those out. You need to establish the limits; you are finding the boundaries of the puzzle. You start thinking about the possibilities. Unlike a jigsaw puzzle, there are generally many ways the pieces of the puzzle can fit together in the form of a lab or building design.

Who are the team players in the programming process other than the designers? This depends on the project. For a small renovation of a research lab, they may simply include the researchers and the project manager on the university's side. If it is a larger project, the team will be larger. It should consist of the owner. This may be the department head who is funding the project, such as a department chair or a dean. The users should also give their input if they are known. Sometimes, colleges need to construct research lab space before it is determined who will occupy it. Lab managers also provide valuable input. If it is a teaching lab, the faculty who teach in the space will be able to let you know how they teach and what they need to do the job. The facilities maintenance personnel or someone who knows the campus systems and building standards should also be involved. They are particularly helpful for renovation projects. You are going to need to document the existing engineering systems. Do not forget Environmental Health and Safety (EH & S); their requirements may differ from building code requirements. Eventually, IT and AV Managers need to be involved as well as the campus police.

Once your team is established, gather information. You can always start with the 5 W's – who, what, when, where, and why. You need to know whom you are designing for. Are you designing for students? Will the lab be used by a single researcher and their team? Maybe a group of researchers will be occupying the space. How many people will be utilizing the lab, and what are their roles?

Next, what will you be designing? Is this a class lab for the Chemistry department? Is it a specialized research lab that uses lasers? Is it a brand-new building? What are the functions of the lab? If you are renovating an existing lab or if a PI (principal investigator) is relocating from one lab to another lab, ask what works well for them now; what doesn't work? What are the key concerns to be addressed with the current project?

When does the space or building need to be ready for occupancy? Does it need to be ready before the start of the Fall semester? Is the new PI coming in 6 months, and they have been promised a newly renovated lab upon their arrival? Or maybe there is a grant that got approved, and the research must be done in a certain amount of time.

Where is the project located? Is it in the basement of one of the science buildings? Is a new building being constructed? Maybe it is a building addition that is included in the campus master plan.

Finally, why is this project necessary? Is your client preparing for future growth? Is there a donor that contributed a large sum of money for a specific purpose? Do you want to improve functionality? Oftentimes, labs simply need to be brought into the 21st century with more energy efficient fume hoods and LED lights, new casework, and updated finishes.

Once you have gathered the general information for the project, get into the details. For most labs, one of the most important things you will need is an equipment list. This will include typical lab equipment such as centrifuges, water filtration systems, and ultra-low freezers. You also need to know if miscellaneous items that consume wall space like markerboards and periodic charts are necessary. Below is a list of equipment information that should be collected:

- Size of each piece of equipment
- Location: floor, workbench, wall, or hung from the ceiling
- Clearance requirements above, below, and around it
- Required adjacencies to other equipment
- Specific mechanical requirements
    - Heat gain
    - Exhaust
- Power requirements
    - Emergency power required
    - Dedicated circuit required
    - Amperage
    - Phase
    - Specific receptacle type
    - Can it be plugged into GFCI?
    - Specific lighting (Lasers are an example as they generally need a dark room.)
- Plumbing requirements
    - Compressed air
    - Vacuum
    - Distilled water
    - RO water
    - Gas
        - Building

            - Cylinder
- Miscellaneous requirements
    - Sensitivity to vibration (Microscopes, balances, and lasers are examples.)
    - Sensitivity to natural light
    - Network requirements

If the equipment is existing, review and document each piece yourself. Get all cut sheets that are available. Talk to equipment representatives about new pieces that are being purchased. Programming interfaces such as Dynamo and AutoLISP may be helpful for larger projects. The equipment information can be imported directly into the BIM model or CAD drawings to create equipment plans automatically.

Another major design factor is related to the chemicals and quantities that will be used in the lab. It is especially helpful if you can be provided with a list that includes the properties, storage requirements (such as needing to be stored in a locked, flammable storage cabinet), ventilation requirements, or any other special requirements. Are they corrosive? Are they sensitive to heat or humidity? Are they an aggressive staining agent? Are they required to be separated from other chemicals?

Storage can take up a lot of space in the form of casework, shelving, or actual storage rooms, so it is also important to find out the storage needs. What equipment needs to be stored and in what way? Where do personal belongings and personal protective equipment (PPE) get stored? What miscellaneous items need to be stored? This could include field gear such as coolers and shovels. There is also a chance that someone’s lifelong research work must be stored.

Most class lab coordinators have a specific way they distribute equipment. Each student or team may be issued a set amount of equipment at the beginning of the semester. It is important to find out if the equipment should be stored in drawers or in cabinets with shelves. Find out how many students or teams must be accommodated each semester. If the cabinets should be keyed, in what way? Students may bring their own padlocks to secure the equipment.

With COVID, the distribution and return of PPE has changed at some universities. For example, there are vending machines that can dispense freshly sanitized coats. Students check out lab coats by swiping their ID’s. At the end of class, they swipe their ID’s again and put their coats in the return slot. Contracted companies pick up, launder, and restock the coats each day.

Once you have the basic information about the project, get into the details. Discover the exact workflow and processes for the lab. Find out what is expected to happen from the point of entry to once they are inside the lab. Do students leave their belongings and drinks outside in the corridor? This would create the need for lockers or cubbies. Is a badge swiped to gain access to the lab? If there is an existing lab that functions similarly to what you are designing, go there. See what tasks they perform and in what order. Once you find out how they currently operate, ask them what could be done differently to improve the flow, efficiency, comfort, or productivity.

Once you gather the information, you can start thinking about the design. How are the puzzle pieces going to fit together?

REVIEW QUESTIONS

1. Which of the following information is not important during the programming phase of the renovation of a 1,000 s.f. chemistry lab?
   a. The types and quantities of chemicals that will be used
   b. If it is a teaching lab or a research lab
   c. The budget for the project
   d. The owner's preferred color scheme

Part 2: DESIGN CONSIDERATIONS

CHEMICALS

There are many design considerations. One of the major ones involves chemicals. The quantity and type of chemicals will determine how much space they take up. How they are used determines if they get stored in a chemical storage cabinet under a fume hood or in a prep room. Equipment using chemicals may need to be exhausted, depending on the chemical type. There is equipment specifically designed for exhausting chemicals, such as a fume hood, that needs to get connected to exhaust ductwork. Some chemical storage cabinets may need to be vented, as well. The need to vent either equipment or storage cabinets will affect the placement of the equipment because you want to minimize the duct runs, if possible, to the main exhaust duct lines.

FINISH SELECTIONS

Chemicals have a role in finish selections. Corrosive cabinets need to be painted with a corrosive resistant epoxy coating. The type of coating needed inside fume hoods is also dictated by chemicals and concentrations used. Uncoated fume hoods can only be used for clean air applications such as supply air or general exhaust. Phenolic and/or stainless-steel parts are typical for most fume hood applications. Phenolic with no exposed metal is required when exhausting chemicals corrosive to metal such as chloric acid.

BUILDING CODE REQUIREMENTS

There are building code requirements based on the type and quantities of chemicals. Common codes that must be followed are the NFPA 45, which is the National Fire Protection Association's code for Fire Protection for Laboratories Using Chemicals, the IBC, or International Building Code, and the IFC, or the International Fire Code. The various codes differ, so find out which codes your jurisdiction have adopted. A lot of universities have their own fire marshals, so it is a good idea to sit down with them to see what their expectations are. They may require something that exceeds the code requirements.

Both the NFPA and IBC/IFC limit the quantity of hazardous materials that can be placed in a lab. To figure out what the limits are, you (or your client) need to have an idea of the chemical flash points for the chemicals that will be used and/or stored in the lab(s). Once you know what the flashpoints are, the chemicals can be classified per *NFPA 30 - Flammable and Combustible Liquids Code*. In the 2021 version, the classifications may be found in chapter 4.

Type	Class	Flashpoint	Boiling Point
Flammable	IA	<73°F	<100°F
	IB	<73°F	>100°F
	IC	≥73°F and <100°F	
Combustible	II	≥100°F and <140°F	
	IIIA	≥140°F and <200°F	
	IIIB	≥200°F	

Summary of *NFPA 30* Classes of Flammable and Combustible Liquids

The IBC/IFC and NFPA differ on chemical quantity limitations. NFPA's limits are related to the size of the lab and the material class of each chemical. *NFPA 45* provides the limits on Table 9.1.1 (Maximum Quantities of Flammable and Combustible Liquids in Laboratory Outside of Inside Liquid Storage Areas). All limitations shown on the table must be met concurrently for the use and storage of hazardous chemicals.

Fire Hazard Class	Material Class*	Maximum Quantity in Use, gal		Maximum Quantity in Use and Storage, gal	
		per 100 ft^2	per Lab	per 100 ft^2	per Lab
A — High Fire Hazard	I	10	480	20	480
	I, II, IIIA	20	800	40	1,600
B — Moderate Fire Hazard	I	5	300	10	480
	I, II, IIIA	10	400	20	800
C — Low Fire Hazard	I	2	150	4	300
	I, II, IIIA	4	200	8	400
D — Minimal Fire Hazard	I	1	75	2	150
	I, II, IIIA	1	75	2	150

Summary of *NFPA 45* Table 9.1.1 Limits

NFPA also has limitations on the hazardous chemicals that can be used and stored in a building above the third floor. Type A hazard classifications are not permitted above the third floor. Labs that have a B fire hazard class are limited to 50 percent of the maximum quantities on levels three through six and are not permitted above the sixth floor. Classes C and D are limited to 75 percent of the maximum quantities on levels three through six and limited to 50 percent on levels seven through nine. (The floor limitations are spelled out on the footnotes of *NFPA 45* Table 9.1.1.)

The IBC and IFC's hazardous material limits are based on sizes of control areas and material classes. The control areas are defined areas in the building where the hazardous materials will reside and be used. The quantities of hazardous materials cannot exceed the maximum allowable quantities listed in the code. Otherwise, the area would have to be classified as an H occupancy rather than a B occupancy. If the building is sprinkled, these quantities can be doubled. If the hazardous liquids are kept in approved storage such as a gas cabinet, the quantities can be doubled again. A control area can be a single lab or a group of labs. If it is a group, there may be some non-lab rooms that fall within the control area. The control area is required to be separated from other areas of the building with fire-rated separations. The higher the laboratory unit's fire hazard classification is, the more restrictions there will be on its size, fire rating, and how high they can go in a building above grade. The maximum allowable quantities are shown on *IBC 2021* Table 307.1(1). As with NFPA's requirements, there are limitations on quantities stored and quantities that are in use. The IBC defines storage as the keeping, retention or leaving of hazardous materials in closed containers, tanks, cylinders, or similar vessels; or vessels supplying operations through closed connections to the vessel. IBC differentiates between those that are used in closed systems and those that are used in open systems. A closed system does not allow the chemical vapors to be exposed to the atmosphere, such as a product conveyed through a piping system into a closed piece of equipment. An open system allows vapors to get into the atmosphere, such as dispensing from open beakers or containers.

Material	Material Class	Storage, gal	Use (Closed Systems), gal	Use (Open Systems), gal
Combustible Liquid	II	120	120	30
	IIIA	330	330	80
	IIIB	13,200	13,200	3,300
Flammable Liquid	IA	30	30	10
	IB and IC	120	120	30
Combination Flammable Liquid	IA and IB and IC	120	120	30

Excerpt of Maximum Allowable Quantities from *IBC 2021* Table 307.1(1)

The IBC and IFC also puts a limitation on the number of control areas per floor. In *IBC 2021*, this is summarized on Table 414.2.2. Note that the quantities decrease the higher you get in the building. So, you are likely not going to have a lab building that is higher than three floors unless there are little or no hazardous chemicals used on the upper floors.

Floor	Maximum Control Areas per Floor	Maximum Percent of MAQ per Control Area	Maximum MAQ Increase per Floor
1	4	100%	400%
2	3	75%	225%
3	2	50%	100%
4	2	12.5%	25%
5	2	12.5%	25%
6	2	5%	10%
7–9	2	5%	10%
>9	1	5%	5%

Maximum Allowable Quantities per *IBC 2021* Table 414.2.2

EXHAUST SYSTEMS

Types of chemicals and agents will also determine the types of exhaust systems that will be utilized. There are snorkels, fume hoods, biosafety cabinets, and glove boxes. Snorkels are suitable for the removal of heat or irritant fumes, such as at soldering stations. If snorkels are needed in an electronic environment, there are ESD (or electrostatic discharge) models that have an extraction arm made of conductive materials to eliminate the risk of static electricity.

The snorkel exhaust is bending down from the ceiling in this image.

Fume hoods are appropriate when working with gases, vapors, and fumes that need to be vented. There are ducted and ductless fume hoods. Ductless hoods are useful for controlling odor and dust. They have fans that suck the fumes back into HEPA and carbon filters. Since filters must be changed frequently, they are not as reliable as a ducted fume hood because you must rely on proper maintenance which may not happen. Some campuses do not allow them.

For ducted fume hoods, there is an exhaust fan on the roof that pulls the air through the exhaust ductwork and exhausts it into the atmosphere. There are constant volume and variable air volume fume hoods. The constant volume hoods incorporate a bypass feature that allows a constant volume of air to be exhausted through the hood regardless of the sash position. The exhaust volume for variable air volume hoods varies depending on the sash position. Only the amount of air needed to maintain the specified face velocity is pulled from the room, so there can be a significant amount of energy savings if the sashes are kept closed much of the time. Some fume hoods come with presence sensors that trigger a setback mode or automatically close the sash. If there is a lab with poor sash management, this would be a good option. In some jurisdictions, it is a requirement.

Fume hoods are not capable of containing explosions, even when the sash is fully closed. If an explosion hazard exists, shields or strong enclosures that can deflect or contain the explosion need to be installed. Barriers like this can significantly affect the airflow in the hood.

A conventional fume hood cannot be used for perchloric acid. Perchloric acid vapors can settle on ductwork, resulting in the deposit of perchlorate crystals. Shock-sensitive perchlorates can accumulate on surfaces and have been known to detonate on contact. This can cause serious injury to researchers and maintenance personnel. Specialized perchloric acid hoods, made of stainless steel and equipped with a wash-down system must be used. The exhaust fan needs to be acid resistant and spark resistant. The exhaust fan motor and drive belts should not be located inside the ductwork. Ductwork for perchloric acid hoods and exhaust systems needs to be on the shortest and straightest path to the outside of the building. They cannot be manifolded with other exhaust systems. Horizontal runs must be as short as possible, without sharp turns or bends. The ductwork needs to maintain a positive drainage slope back into the hood and be sealed. Flexible connectors cannot be used.

Work involving harmful microorganisms should be done in a biosafety cabinet rather than a chemical fume hood. A biosafety cabinet filters the potentially contaminated air through high efficiency particulate (HEPA) filters, and then vents that air back into the room. For this reason, chemical fume hoods cannot be used when working with hazardous chemicals. There are some biosafety cabinets that are vented outdoors after being filtered; however, they are still generally used to prevent contamination and infections from microorganisms.

In this image, there are four biosafety cabinets next to a fume hood.

Well-designed fume hoods are capable of containing 99.9999% of the toxins released within them when used correctly. (Princeton University, 2023) When working with highly dangerous substances needing more containment than a fume hood offers, a glove box should be considered. They contain the highly toxic chemicals and agents.

Glove boxes may be used under positive or negative pressure. Glove boxes operated under positive pressure usually contain materials sensitive to outside contaminants such as air or water vapor. Exposure to outside contaminants can lead to degradation or a violent reaction with these compounds. Negative pressure glove boxes are used to protect workers from toxic gases or pathogens.

This image shows gloveboxes in a research lab.

When additional fume hoods will be installed in a building during a renovation, it a good idea to go on the roof and see where another exhaust fan can be placed. This will help determine where to put a new chase if an existing exhaust fan cannot simply be replaced with one of a higher capacity.

Chemical exhaust fans on a roof can be seen here.

FLEXIBILITY

Flexibility is a huge factor when it comes to designing labs, especially research labs. If most of the storage and workbenches can be moved around, fewer renovations are required in the future when there is a new PI in the space.

Plant and Soils Science lab

The photo of a Plant and Soils Science lab shows fixed cabinets around the perimeter of the lab. The moveable workbenches and storage are in the middle of the lab. Utilities are brought in from below, routed through the vertical bench supports and into the power strips at the back of each bench. The storage cabinets below the workbenches have casters, so they can be easily moved around.

Mechanical Engineering lab

In the mechanical engineering lab shown, you can see that there were no upper shelves, and the benches do not have casters because large heavy equipment was going to be placed on them. The storage cabinets below the benches have casters, so they can be moved around easily. Power comes from the reels above.

Flexible lab

The flexible lab shown in the image was constructed before its occupants were known. The workbenches in the middle of the lab are on casters, so they can be easily reorganized. The storage below them are also on casters. There are some workbenches around the perimeter that are freestanding and can be moved. Sinks are on perimeter walls and set in fixed base cabinets. The fume hoods are located towards the exterior wall with fixed chemical storage cabinets below them.

This image is a close-up of a plug-and-play overhead service carrier.

This photo shows a different type of plug-and-play panel.

Adaptable engineering services can be designed that also include supply and exhaust air, water, electricity, voice/data, and vacuum.

If you are designing a new building instead of a renovation, it is a good rule-of-thumb to design the engineering systems to service the initial anticipated demand and at least 25% for future programs. (Watch, D., 2016) The mechanical system should be sized so that fume hoods can be removed and added. Size the ductwork for the maximum number of hoods for the building to allow for change and growth. Vertical exhaust risers can be provided for future fume hoods in the initial construction. Of course, re-balancing of the mechanical systems after each fume hood addition will be necessary.

It is a good idea to allow for maintenance of the controls outside the lab. In new labs, put the service shutoff valves in a box in the wall at the entrance into the lab or in the ceiling at the entry.

For new research buildings where the PI's moving into the labs are not yet known, allow for swing space. Allocate around 25% of space for equipment zones. Only 50-70% of the casework should be installed initially. (Watch, D., 2016) The rest of the lab can be fitted out later when the exact needs are known. Zones for cylinders should be located on the outside walls near the fume hoods. Refrigerators should be placed on the perimeter. Only sinks and fume hoods should get stationary casework.

Swing space

In the example swing space photo, there is a sink cabinet and a moveable workbench. You can see the overhead service carrier in the middle of the room. The rest will be customized for the PI's specific needs.

Increased flexibility can also be provided with mobile partitions or technology carts that can be moved from lab to lab.

BUDGET

Flexibility

A lot of design elements are going to be determined by the project budget. Even though most researchers want flexible labs these days, flexible casework has a 20-35% increase in cost over fixed casework. (2023, Brader & Bartlett) Storage cabinets on casters have counterweights in them to prevent tipping and need to be finished on all sides. So, the upfront cost is more. However, the amount that can be saved over the lifetime of the lab can make it worth it. If it is a teaching lab that is likely to remain the same over the years, it does not make sense to install moveable workbenches and plug-and- play overhead utilities. For a research lab that is likely to see many PI's and different types of research over the years, it makes sense to allow for flexibility. This reduces the cost and time of future renovations.

First-cost vs. Lifetime cost

Something that needs to be considered when making decisions based on budget is that the lowest first-cost design/product selection options may increase the risk for those using the facility and laboratories within an educational facility. For example, installing ductless fume hoods will save a lot of cost up front, but they are likely to not perform as they were designed to perform in the future because filters do not get changed as often as they should.

Variable air volume hoods cost more up front and require more maintenance than constant volume hoods. However, there will be significant cost savings in energy if the sashes are left closed most of the time.

Finishes

The finishes selected can have a huge impact on the budget, as well. Epoxy flooring may be one of the best choices for a lab. However, it can also be one of the most expensive. When factoring in the longevity and performance of the epoxy, it can be considered a cost-effective solution. Polyurethane resin flooring is similar in cost to epoxy. Vinyl flooring with heat-sealed seams is more cost-effective. It is not as friendly to the environment though because vinyl is not biodegradable. If you damage a part of the floor, you will need to throw out the entire panel and have a new one installed. The most economical option is probably sealed concrete. That depends on the condition of your existing concrete floors. Floor prep costs add up quickly.

Of the various countertops out there, chemical-resistant plastic laminate is the cheapest option for a wet lab. You need to consider how it is going to be used. Laminate may not provide the heat resistance and longevity that is required. Epoxy is generally the most expensive type of lab countertop.

Type of Furniture

Even though simple steel stools with hardboard seats are probably the least expensive option, they are generally the least comfortable option, as well. Polyurethane stools with backs are more costly, but they tend to be much more comfortable.

Control Area Classification

One other potential budget consideration relates to how the control areas are classified. Generally, the owner estimates the quantities of hazardous materials based on what is done in existing labs and facilities. However, if a PI moves into the lab later and uses enough quantities to increase the fire hazard class, this could bring about costly renovations. It may be wise to over-specify the fire hazard classification to account for future possibilities. This could be done to a limited number of labs if it is cost prohibitive.

TECHNOLOGY

The required technology is another design consideration. Oftentimes, there are pieces of equipment in a lab that must be connected to a computer. Writeup areas generally have computers. It is important to know the number of stations required. The university may have a standard setup that each investigator receives.

If a lab is a teaching lab, it is common for them to have overhead projectors, projection screens, t.v. monitors, and A/V racks.

Augmented or virtual reality is being used in more labs these days. Augmented reality presents information in an immersive way by superimposing data and digital images on objects in real-time. This has been shown to help students absorb and apply the information better. If augmented reality or virtual reality will be used, you need to design a place for it to be stored and charged. Understanding how it will be used is required. A zone may need to be designed specifically for it.

3D printers are appearing in more labs. Additional exhaust may be required because they put off fumes. If multiple printers are placed in the same lab, the heat load needs to be considered.

Gross anatomy lab

Technology has a large roll in how gross anatomy is taught in the lab shown in the image. The large monitors at each workstation display the camera view of what the professor/doctor is teaching at the front of the lab. The cameras and monitors allow the instruction of a much larger class. It also allows the class to be taught more efficiently.

HEAT LOAD

Heat load is another design consideration. Everything that plugs in is going to produce heat. Some equipment puts off more heat than other equipment. To efficiently design the mechanical system, the high heat-producing equipment such as ultralow freezers, refrigerators, and centrifuges should be placed together in a room, if possible. If designing a renovation, it is helpful to inquire with campus maintenance about any issues with the existing HVAC equipment keeping up with cooling. If the HVAC equipment is not sized appropriately and the temperatures are not kept at an optimal level, the lab equipment's life is going to be reduced.

SIZE OF EQUIPMENT

It is obvious why size of equipment is a design consideration. A common mistake is neglecting to take into consideration how the equipment or furniture is going to get from the loading dock into the labs. If there are large pieces of equipment, it is wise to take the path from outside the building, through the exterior doors, up or down the stairs or elevators, down the corridor, and into the room to ensure there are sufficient clearances everywhere. You also do not want to permanently trap equipment.

The photo here shows an NMR (nuclear magnetic resonance) that was being prepared for a move to another building.

UNIVERSITY ENVIRONMENTAL HEALTH & SAFETY REQUIREMENTS

The specific EH & S requirements of the university are another design consideration. Most universities have manuals that list their lab requirements. For example, cup sinks may not be allowed in fume hoods. For the same reason, floor drains are forbidden in some labs, as well. Certain chemicals should not be introduced into the sanitary sewage system.

BSL RATING

Each BSL (Biosafety Level) rating has its own list of design requirements. BSL refers to the ascending levels of containment for handling biological agents that pose different levels of risk to the workers and the environment. This consists of a combination of lab procedures, practices, safety equipment, and lab facilities which allow manipulation of biological agents of increasing danger to life and health. The CDC (Centers for Disease Control) and NIH (National institutes of Health) put forth a document called the BMBL, or Biosafety in Microbiological and Biomedical Laboratories, that lays out these levels from 1 – 4. These levels build on each other as the containment needs increase.

	Agents	Practices	Safety Equipment (Primary Barriers)	Facilities (Secondary Barriers)
BSL1	• Not known to consistently cause disease in non-immunocompromised adults; minimal hazard to personnel & environment	• Standard Microbiological Practices • Biohazard warning signs as appropriate	• No additional safety equipment required. • PPE: protective clothing and eye/face protection; gloves. • Long hair secured.	• Sink • Door • Eye wash • Windows are sealed or fitted with screens • Impervious surfaces • Adequate lighting
BSL2	• Associated with human disease; moderate hazard to personnel & environment • Primary routes of exposure routes are percutaneous injury, ingestion, mucous membranes • Human materials, clinical samples, and unknowns	BSL-1 practice plus: • Limited access • Fever monitoring or other medical surveillance as determined by risk assessment. • Equipment and lab are regularly decontaminated.	• BSC and other physical containment devices used for manipulations of agents when splashes or aerosols may be generated • PPE: Barrier lab coats are preferred. Additional PPE as dictated by risk assessment (i.e. double gloves, respirators, etc.).	BSL-1 plus: • Autoclave available • Self-closing doors • Vacuum lines are protected by both liquid disinfectant traps and in-line HEPA filters or their equivalent • Sink preferred at exit • Sealed windows are preferred
BSL3	• Agent may have serious or lethal consequences • Primary route of exposure is inhalation • Materials likely to contain such agents (indigenous or exotic).	• BSL-2 practice plus: • Controlled access • Decontamination of all waste • Decontamination of lab clothing before laundering • Medical surveillance required • All agents are transported as Category A	• BSC or other physical containment devices used for all open manipulations of agents • PPE: protective lab clothing; double gloves; eye/face protection; respiratory protection as needed	BSL-2 plus: • Physical separation from access corridors • Double-door access • Exhausted air not recirculated • Negative airflow into laboratory • Hands-free sink at exit and each zone • Sealed penetrations • Designed for complete decontamination • Negative airflow with visual monitoring

Partial Summary - Recommended Biosafety Levels for Infectious Agents

This Biosafety Levels table is a summary of the recommended biosafety levels. The far-right column translates these levels into the design elements. For example, moderate hazard labs that get categorized as a BSL2, such as a lab where blood gets drawn, will need a sink, a self-closing door, an eye wash, adequate lighting, impervious surfaces, an available autoclave, and vacuum lines with traps and HEPA filtration. BSL4 labs are typically not located on university campuses, so it is not shown. Some universities will not allow BSL3 labs, either.

EXHAUST REQUIREMENTS

Depending on the chemicals being used, their specific exhaust requirements can affect the design. Certain chemicals will require specific types of exhaust. The various exhaust methods were described earlier. EH & S may have specific requirements, as well.

PPE

The PPE plays a role in the design because it will require storage somewhere. Due to contamination, coats may not be allowed to be stored in offices or public areas. Some labs require the students to bring their own lab coats. Others provide them. The same is true with safety glasses.

SIGNAGE

Each lab has signage requirements. If EH & S's signage requirements are not identified and incorporated into the design, signs will be taped all over the walls upon construction completion. Space can be allocated at the required signage locations in the lab by providing tackboards, poster cabinets, or sign holders. The standard lab signage that goes on the exterior of the lab could be incorporated into the design for the room signs.

FOOD/BEVERAGE

Eating and drinking is not allowed in most labs. It is important to consider where occupants can eat or safely leave their food outside the lab to prevent random tables being placed in corridors for this purpose. Lockable storage may be preferred by the students; however, it could also be used to store weapons or drugs.

SAFETY

There are various design elements that can increase safety within a lab. Below is a consolidated list.

- If building gas is used, there needs to be a gas shut-off valve.
- All pipes, valves, and clean-outs need to be clearly labeled. Labels should include contents, pressure, and temperature.
- Warning sensors should be installed that automatically shut off utilities.
- Specify freezers with alarms so that when the temperature drops below desired levels, an alarm will sound.
- Wall space needs to be allotted for fire extinguishers.
- Building codes or even the campus insurance company will dictate where fire suppression goes and what type is required.
- Hard hats will take up a lot of space if they are required.
- Leak detection in chemical storage cabinets is advisable. There are spot detectors, cable detectors, or combo detectors.
- Slip-resistant flooring is important in any lab.
- If chemicals are being used in the lab, the flooring should be chemical resistant. Poured epoxy flooring is a good solution because it can have an integral cove base, and it does not always need seams. It is also easy to maintain.
- Eye washes are required where chemicals are being used. Safety showers may also be required.

- AED’s are more common now. So, check to see if your client wants one in their lab.
- There should be a chemical or biological spill kit where appropriate.
- Glass disposal and hazardous material disposal need to be provided. This may simply be something that the lab users or EH & S provides, but it is always good to ask.
- The countertops in fume hoods should have raised edges to help contain spills. It is a good idea to specify raised edges along the outer edge of shelving, as well, to prevent items from slipping off.
- In student labs with chemicals or expensive, sensitive equipment, stools with glides may be preferred over stools with casters.
- Another common request is to install data loggers on the ultra-low freezers. If the power goes out or the temperature drops below a set temperature, the PI will be notified remotely. Data drops or network ports are usually required.

This is a recessed combination safety shower and eye wash station. The handle on the left pulls down to expose the eye wash.

SECURITY

DURABLITY

Another design consideration is durability. Lab furniture comes with varying finishes. Cabinets can be wood, steel, plastic laminate, or stainless steel. Countertops can be plastic laminate (this may be a high-pressure laminate or a chemical resistant laminate). They could also be stainless steel, phenolic resin, or epoxy resin. To be durable, countertops need to be compatible with how they will be used. Epoxy resin countertops are chemical resistant, non-conductive, stain and heat resistant. But, they scratch easily. Usually, the lighter color epoxy hide scratches better, but black is still the most common color.

Phenolic resin counters have great chemical resistance, are nonporous, and are UV, heat, bacteria, and scratch resistant. They are less heat resistant than epoxy resin, though. If the countertops are going to be exposed to heat greater than 350 degrees, epoxy resin should be specified because it can handle higher continuous heat loads including open flame better.

Stainless steel is another option for countertops. However, they are not as chemical resistant as epoxy and phenolic, and they scratch easily. Stainless steel is generally specified for labs where biocontainment is a factor such as animal dissection labs or gross anatomy labs.

Chemical resistant plastic laminate is the least expensive option and could be adequate for low-use labs. The downside is that you won't get the longevity as you would with the other options. They do not have the heat resistance and chemical resistance as epoxy and phenolic do.

Polyurethane resin flooring is more heat resistant than epoxy. So, they would be the preferred choice for labs that deal with instruments and equipment at high temperatures. Even though sealed concrete can be very durable, it is more prone to cracking with temperature changes. If the lab experiences temperature fluctuations, sealing the concrete may not provide the durability that you need.

Most labs have stools. Fabric should not be used. There are polyurethane stools that are chemical and puncture resistant that could be installed instead. Another option is a stool that is cut polyurethane foam material upholstered with durable vinyl. Along with durability, comfort and ergonomics of the stools should also be considered. If they are not comfortable, they are more likely to be replaced sooner rather than later. Steel and hardwood stools are options for labs where users are not sitting for long periods of time.

Lab casework is generally wood or steel. Both are very durable. Wood costs less than steel. If there are staining agents or high heat in the lab, it is advisable to go with steel. Sometimes, it comes down to preference. Steel is oftentimes specified for wet labs. You can get wood veneer or plastic laminate fronts put on the steel cabinet doors and drawer fronts if you want the warmer look that wood brings. Wood casework is more common in dry labs such as geology or archaeology labs.

RESEARCH OR TEACHING LAB

Another design consideration is if the lab is a research lab or a teaching lab. Mobile casework is preferred in a research lab if the budget allows. Research labs are also more constantly occupied. They have strict containment requirements. Control of the temperature is important. Finally, the fume hoods are most likely not going to be used simultaneously, so you can benefit from the codes that allow the size of some of the mechanical components to be reduced.

Teaching labs are more likely to have fixed casework unless there are plans to convert it into a research lab in the future. Teaching labs accommodate a larger number of people. Less airflow is required during unoccupied times, but the fume hoods are more likely to be used simultaneously.

WET LAB OR DRY LAB

Wet and dry labs have different design requirements, as well. A wet lab is a lab where it is necessary to handle various types of chemicals and potential wet hazards. A dry lab has dry materials, electronics, and large instruments with few piped services. Humidity and dust control are very important.

Wet labs are obviously going to have sinks. Due to this, at least some of the casework will likely be fixed. Fume hoods are common in wet labs. They will also have piped gases and chemical resistant countertops. One hundred (100) percent outside air is probably required.

Dry labs are usually computer intensive. Their air can be recirculated. A higher cooling load may be required due to the amount of heat generated by the equipment.

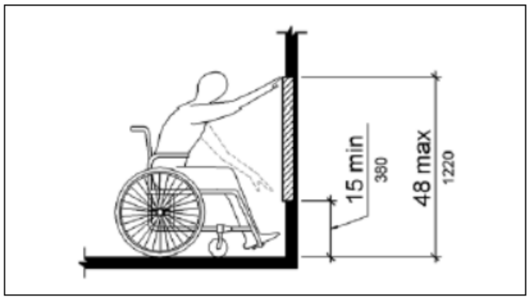
ACCESSIBILITY

Another design consideration is accessibility. You should check with your local jurisdiction to see what accessibility code(s) they have adopted. This course will provide the requirements from the *2010 ADA Standards for Accessible Design,* referred to as *Standards* hereafter.

Anything built or altered must comply with the *Standards*. That does not mean that every single element must be accessible. The *Standards* tell you what and how many of each element must be accessible. One big exemption is employee work areas. Section 203.9 states that spaces and elements within employee work areas shall only be required to comply with 206.2.8 (circulation path), 207.1 (means of egress), and 215.3 (fire alarm) and shall be designed and constructed so that individuals with disabilities can approach, enter, and exit the employee work area. If a lab is ONLY being used by employees, it is not required to have the same accessible elements that a teaching lab does. However, if the lab is going to have student workers or lab assistants that are not being paid to work in the lab, they need to be accessible because they are not just employee work areas.

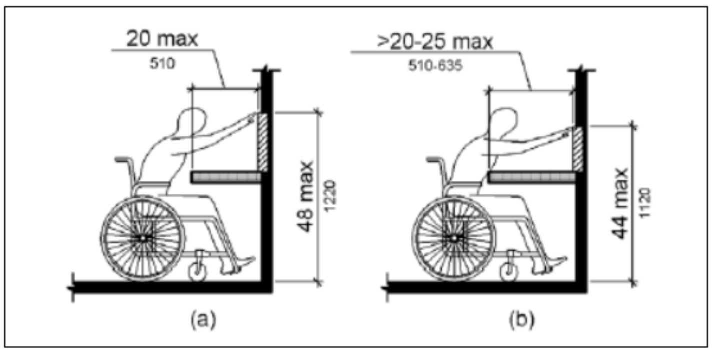
If the decision is made to NOT include all of the accessibility elements initially, it will be required in the future if someone on staff needs those accommodations. Making a lab accessible after the fact is much more expensive than designing it that way up front. Oftentimes, disabilities are temporary due to an accident or procedure. If a researcher cannot use their lab due to a temporary disability, this could have a very negative impact on them and their research.

Figure 308.2.1



Unobstructed Forward Reach

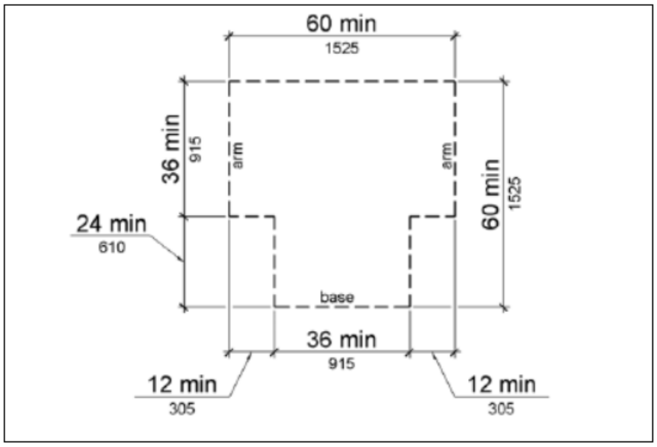
Figure 308.2.2



Obstructed High Forward Reach

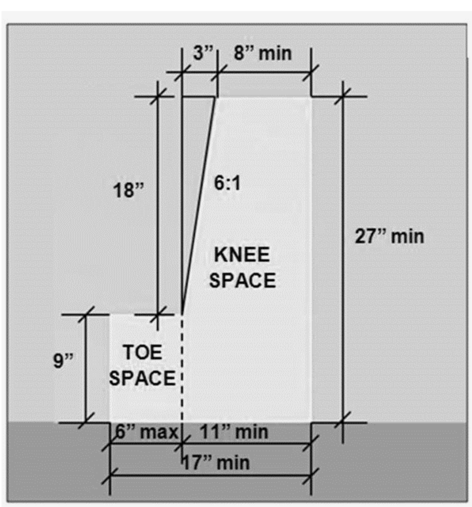
Teaching labs have several elements that must be accessible. If lockers are positioned in the corridor for the lab, at least five (5) percent must be within accessible reach ranges as shown in Figures 308.2.1 and 308.2.2 taken from the *Standards*. At least one accessible entrance into the lab is required with at least 32 inches of clearance; a 36-inch wide door is the standard width that is accessible. Clear floor space around the door for maneuvering is necessary, as well. Requirements may be found in Section 404 of the *Standards*. Adequate aisles must be provided that are at least 36 inches in width. Turning spaces are necessary, too. Either a 60-inch diameter circle or a T-shaped space that takes up a 60 inch by 60 inch area is required. This is shown on Figure 304.3.2 from the *Standards*.

Figure 304.3.2



T-Shaped Turning Space

At least five (5) percent but no fewer than one (1) of each type of sink must be accessible. So, if there are cup sinks and standard sinks in the lab, at least one (1) of each must have adequate knee clearance under it at a height of twenty-seven (27) inches and below. The top rim of the sink cannot be higher than thirty-four (34) inches. The faucet controls need to be the lever type (not knobs) and placed within accessible reach ranges. The paper towel and soap dispensers located at the accessible sinks need to be within accessible reach ranges. They should not become protruding objects by protruding into the circulation paths more than four(4) inches between the heights of twenty-seven (27) and eighty (80) inches.



Knee and Toe Clearances (*United States Access Board Guide to the ADA Standards)*

At least five (5) percent of worksurfaces must be accessible (Sections 226, 902). A forward approach clear floor space must be provided that has adequate knee clearance. If a worksurface is mobile and NOT connected to utilities, it does not apply because the *Standards* apply to fixed elements. However, if the workbench is connected via plug-and-play, five (5) percent should be accessible. Adjustable height workbenches are an excellent option because they accommodate users of various heights.

One of each type of storage provided must be within accessible reach ranges. This would apply to shelves, drawers, coat hooks, etc.

One of each type of exhaust element needs to be accessible. For example, if fume hoods are provided, at least one is required to have a knee space at twenty-seven (27) inches and below, a countertop that is not higher than thirty-four (34) inches, lever handle controls instead of knob controls, and controls that are not higher than forty-eight (48) inches. Please note that the knee spaces do not need to be centered on the fume hood; they may be offset.

Knee Clearance at Fume Hood; For this fume hood to be fully accessible, the knob controls need to be changed out for lever-type controls.

If safety showers are located along circulation paths, they should not be protruding objects. At least one needs to have controls that are within accessible reach ranges, so they should not be higher than forty-eight (48) inches.

At least one eyewash station must have controls within accessible reach ranges. The eyewashes that have drench hoses are preferred at accessible stations because they accommodate users at any height. The code does not specifically address the optimal height for a person in a wheelchair because there are many different types of wheelchairs that allow users to sit at a wide range of heights.

Miscellaneous considerations include the location of technology elements. T.V.'s should not become protruding objects that protrude into aisles more than four (4) inches at a height below eighty (80) inches. If students will be using A/V equipment, the controls for the equipment must be within accessible reach ranges.

Accessible Sink and Eye Wash

AESTHETICS

The final design consideration for this course is aesthetics. Aesthetics are oftentimes the last design consideration for labs because the primary goal of a lab is to make it functional – not appealing to the eyes. If you are designing a lab for new students, why not try and make it a space where students like to be? The ceiling is a good place to start as you can see in the picture of this organic chemistry lab. A hexagon is the symbol for benzene and makes regular appearances in chemistry courses. Why not incorporate it into the design?

Organic Chemistry Lab

Glass boards on walls in labs provide opportunities for subtle or not-so-subtle graphics. Any image can be printed on the back of a glass board.

Interest can be increased in a lab with the addition of display cases. There are usually more than enough items to display in a lab if you just ask the faculty or staff. Oftentimes, there are very interesting finds tucked away in storage closets that have not been viewed in years. Examples include sand collections in geology labs, archeological remains in anthropology labs, or various specimens in biology labs.

Graphics can add a lot of personality. Vinyl murals are an inexpensive way to get students excited about the field. Murals could include anything from photos of PI's and students working in the field to images of elements that represent the field of that individual lab.

A floor design creates interest that a single-colored epoxy floor does not. A geology lab could have a design of a river running through it. A course for robots may be a pleasant addition on the floor of an electrical engineering robotics lab. Various floor colors could allocate specific workstation zones.

The color in teaching labs need not be boring. Most casework manufacturers make casework in a variety of colors. If color on the furniture is not desired, add color to the walls.

Natural light can make any space more pleasant. If there is a way to introduce natural light into a lab, it may improve the mental health of the users. Of course, it is always a good thing to confirm there will not be any equipment used in the lab that is sensitive to natural light.

REVIEW QUESTIONS

2. What is the maximum height for the top rim of an accessible sink?
   a. 32”
   b. 34”
   c. 36”
   d. 42”

3. Which BSL has the most stringent requirements?
   a. BSL-1
   b. BSL-2
   c. BSL-3
   d. BSL-4

4. What type of exhaust should be provided for the handling of harmful microorganisms?
   a. Snorkels
   b. Fume hoods
   c. Biological safety cabinets
   d. Gloveboxes

5. When designing a flexible lab, which of the following elements are generally designed to be stationary?
   a. Workbenches and storage cabinets
   b. Storage cabinets and sinks
   c. Sinks and fume hoods
   d. Workbenches and fume hoods

6. Which of the following is not a budget consideration when designing a lab?
   a. Should the casework be fixed or mobile?
   b. Should you install epoxy flooring or vinyl flooring?
   c. Should you design for current needs or design for anticipated growth?
   d. Should you install a snorkel or gloveboxes to exhaust hazardous chemicals?

7. Well-designed fume hoods are capable of containing _____% of the contaminants released within them when used properly.
   a. 50
   b. 75
   c. 90
   d. 99.9999

8. If a combustible hazardous material has a flashpoint of 140°F, how would it be classified?
   a. Class II
   b. Class IIIA
   c. Class IIIB
   d. None of the above

9. Which type of exhaust system has the least initial cost for controlling odor and dust?
   a. Snorkels
   b. Ductless fume hood
   c. Ducted fume hood
   d. Biological safety cabinet

10. What is the preferred flooring for a BSL2 lab?
    a. Carpet
    b. LVT
    c. Epoxy with rubber base
    d. Epoxy with integral cove base

Part 3: LAYING OUT LABS

RENOVATIONS

Once you have a clear understanding of the design considerations, you can begin thinking about the layout of the space. If you are designing a lab renovation, first identify where the existing utilities are located. It is more cost-effective to place new fume hoods where existing ones are. If a new mechanical chase is needed, it would be helpful to place new fume hoods adjacent to that chase.

New sinks should go where existing sinks are located, if possible.

If a large piece of equipment is going into the lab, height clearances should be confirmed. Is the ceiling and/or existing HVAC and plumbing high enough for the equipment to fit in the lab without a lot of re-routing?

After placing the elements that need to go in a specific location, bench sizes can be determined. Most manufacturers have a limited selection of sizes, so verify the sizes offered by the manufacturer that will be the basis of your design.

Once the benches are placed on the plan, do test fits. Draw the footprint for every piece of equipment going in the lab. Make sure everything fits where it needs to go. Confirm the required adjacencies for each piece of equipment are possible. Can the necessary engineering services get to each piece of equipment? Consider cost by placing as much equipment as you can near their required utilities. Adjust as needed.

NEW BUILDINGS AND LARGE-SCALE RENOVATIONS

There are other factors affecting the layout that need to be considered. Is the lab going to be open or closed? Open labs have multiple researchers being accommodated in the space. Closed labs are generally for a single researcher and have more specific needs. For research space, there is a push to make all labs open labs so that no lab belongs to any single researcher. For example, a grouping of labs could simply be designed for every type of chemistry-organic, bio, analytical, physical, or inorganic. Common features such as fume hoods could be shared. Other equipment and even support staff could be shared, as well. This cuts down on the cost of labs and the cost of research. More bench space is freed up for each researcher. In an open lab, there should not be a lot of customization designed into it, at first. It needs to leave room for the specific needs of a researcher. For example, do not cover every wall in benches and storage. Leave open wall space that can be filled with what the researcher needs. Maybe they have large pieces of equipment that need to fit somewhere. Or, they can add benches and storage if that is what they need. Of course, there are certain labs that need to remain closed if they are hazardous, have extremely sensitive equipment, or are required by the protocol. Some examples include Nuclear Magnetic Resonance (or NMR), electron microscopes, tissue culture labs, darkrooms, and glass washing.

Equipment needs are going to be a large factor in the layout. Sensitive equipment must be kept away from high foot traffic areas, strong local ventilation, and supply air vents.

If recessed safety showers are not being designed for a teaching lab, they need to be positioned outside of circulation paths, so they are not protruding objects.

It is better to put heavy heat producers such as freezers and refrigerators together. This allows the cooling requirements for the lab to be lowered.

Provide removable shelving above benches, so space for large equipment can easily be created by removing a shelf. The bottom shelf should be nineteen (19) to twenty (20) inches above the benchtop. Make sure the top shelf is no higher than eighteen (18) inches below the ceiling, so the fire suppression system will have adequate coverage.

It is helpful to design data ports next to electrical outlets, so they may be used by computers.

Equipment that requires local ventilation should be kept away from doors, foot traffic, and operable windows.

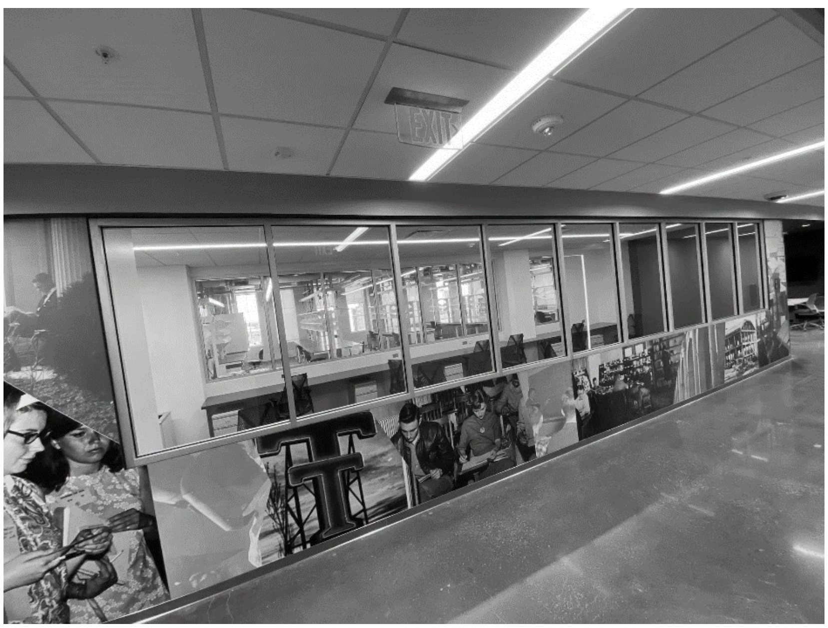
The amount of space needed for workstations or write-up areas can be a determining factor as to where they will go on a plan. Sometimes, it is necessary to put them in a separate room. Other times, they may go inside the lab. Write-up stations need to be at least forty-eight (48) inches wide to allow knee space and hardware under the counter. Workstations should be forty-eight (48) inches wide by thirty (30) inches deep minimum; if shared, it should be seventy-two (72) inches wide by thirty (30) inches deep. Keyboards must be placed away from spill areas.

Graduate Student Room 1

The first graduate student room shown in the image is directly adjacent to the lab it supports. It also acts as a breakroom. The second graduate student room has four (4) feet wide workstations along one wall, a conference table in the middle of the room, a large monitor/t.v. on a nearby wall, and cabinets with a sink on another wall (not shown). It can accommodate team meetings. The technology in the second room creates virtual social spaces. Putting the workstations in multipurpose rooms allows forced collaboration.

Graduate Student Room 2

It is common now to see write-up areas in a room directly adjacent to the main lab with windows, so the lab can still be seen while on the computer. See image with an example.



This is a view of a writeup area from a corridor.

Locating visual obstructions toward the perimeter walls will open up the lab and make it feel less confined. Some of those visual obstructions can be the location of where the utilities are fed. Shelves, fume hoods, and other large equipment will also block your view.

Below are some rules of thumb for placing gas cylinders.

- Compressed gas cylinders should be kept out of public hallways, high foot traffic areas, areas where damage could occur, and out of direct sunlight.

- If a compressed gas cylinder contains an oxidizer, it should be segregated from flammable compressed gases unless they are in use.
- Store gas cylinders away from electrical arc welding as well as stored grease and oils.
- Provide tank supports on the walls adjacent to fume hoods.
- Allow space to secure tanks to the wall in lieu of to workbenches wherever possible.
- Consider tank sizes when positioning the brackets on the wall. Larger tanks may require two brackets, one above the other.

Gas cylinder tank supports on a wall adjacent to a fume hood

DESIGN TRENDS

The concept of transparency with science on display is a major design trend right now. Windows between the corridors and labs increase the connection between the public spaces with the activities going on in the labs. Someone could be working inside the lab and see a group congregating in the corridor. They go join them. Transparency can increase collaboration. It can also demystify the closed-off lab environments by allowing the public to have glimpses of scientific research. Windows can also be considered a safety element. If there is an emergency in the lab, somebody walking by could see it and assist. However, there is the counterargument that windows can make it easy for thieves or terroristic events. A compromise could be to install glass on only the top half of the corridor wall so that occupants can hide up against the lower half of the wall.

This image shows how social elements and transparency can be incorporated into the design of a corridor. Here is an example of the D-shaped desk with a monitor above it. There is a countertop directly next to the entrance into the lab, so food and beverage items could be left there, if necessary, before entering.

Social and collaborative spaces are being designed into buildings. Alcoves can provide a space for impromptu or planned meetings. The addition of technology increases flexibility in the type of meetings that can be had. A coffee shop or deli in the lobby may allow for chance interactions. These interactions increase collaboration which increases innovation.

Flexibility is necessary with every lab design. Earlier, mobile casework and workbenches were discussed for research labs. Teaching labs can benefit from a different type of flexibility. If various teaching resources are designed, instructors can teach in a manner in which they are most comfortable. For example, design whiteboards/glass boards into the layout, but also provide projectors and projection screens or large monitors. Furniture in hybrid class labs that are part classroom and part lab could be reconfigurable for group activities. Power in the furniture allows students to plug in their devices. They can take notes on their laptops, iPads, or even phones. There are apps that allow a student to show the content on their device directly to the large projection screen/monitor in the room. D-shaped tables with monitors allow a group to work independently or as a class.

Sustainability was once considered a design trend by some. However, building codes are being adopted that incorporate sustainable practices, so it is going from a trend to a requirement. The trend may be getting actual certifications such as LEED. Typical lab buildings currently use five times as much energy and water per square foot as a standard office building due to the number of containment and exhaust devices, heat-generating equipment, 24-hr access, and redundant backup systems. (Watch, D., 2016) Some methods to offset the effects of the high amount of energy and water used in lab buildings could be to increase energy conservation and efficiency. Passive energy harvesting through solar power or green roofs can be used for cooling. Chilled beams can be used to cool the air. Heat wheels use energy recovery between devices to reduce the heating and cooling requirements. Implement water conservation methods. Reduce the use of hazardous and toxic chemicals. Provide chemical sensor systems that manage the air quality, so the ventilation rates are only increased when necessary. Provide natural daylight. Incorporate recycling centers into the design. Specify products that have recycled content. Use materials and resources efficiently. These can all offset the impact that labs have on the environment.

Maker spaces are another trend. If you are not familiar with them, they are large open workshop spaces designed to support prototyping and technological testing of theories. They often have 3D printers, waterjets, and CAD-CAM machines. In a research hospital setting, it could include a suite of imaging equipment where new methods and procedures for diagnostic images are investigated. Maker spaces foster innovation and ingenuity where ideas and concepts can be brought to life.

You might say that occupant comfort and wellness have become selling points for potential investigators and students. Natural daylight is a priority, so large atriums are common. When the labs are transparent, natural light is brought further into the building. There are more and more wellness centers for working out and relaxing. Biophilic design is being integrated. Access to green spaces is increased within the interior of buildings through an extension of the exterior landscaping into the interior. Plants improve air quality. Green spaces also absorb sound and promote productive collaboration opportunities. Water is introduced to reduce stress hormones and help improve concentration. Symbolically, you could say that biophilic design establishes a connection with a biology research environment.

Finally, with COVID, there has been somewhat of a shift in design. There has been an increase in distance learning. However, a lot of what is done in a lab cannot be done at home, so labs are still a necessity. More people are working from home or coming in less frequently. This could lower the carbon footprint and improve efficiency. Some universities are increasing compartmentalization to provide separation. (So, some universities went from closed labs to open labs and now back to closed labs!) There has been more integration of the office with the lab. Automation of equipment has been increased so that fewer staff need to be on site. Outdoor meeting spaces are being formed, so meetings can be held while mitigating airborne pathogens. Sometimes, conference rooms are used as a type of vestibule for these outdoor spaces. The pandemic also brought an urgency for better ventilation in office and support spaces. There is more HEPA filtration and bipolar ionization with ducted returns. The level of outside air being introduced back into the buildings has gone up. In some instances, COVID proved that on-site offices are not necessary, so offices are being converted to other things.

As we come to the end of this course, I hope you have a better understanding of what information needs to be gathered during the programming phase, are aware of the major lab design considerations, can lay out functional labs, and have an eye for the current design trends.

Review Questions

11. Which of the following is NOT a result of the pandemic?
    a. Labs are shutting down because the pandemic proved that they aren’t necessary.
    b. Automation of equipment has been increased.
    c. Outdoor meeting spaces are being formed.
    d. Office and support spaces are getting better ventilation

12. Which of the following increases human comfort and wellness in a new lab building?

a. Natural light
b. Access to green space
c. Water features
d. All of the above

13. Which design trend increases collaboration and innovation?
    a. Windows between the corridors and labs
    b. Alcoves with furniture for impromptu meetings
    c. Coffee shop in the lobby
    d. All of the above

14. Which of the following methods can offset the effects of the high amount of energy and water used in lab buildings?
    a. Passive energy harvesting
    b. Chilled beams
    c. Heat wheels
    d. All of the above

15. Typical lab buildings use ___ times as much energy and water per square foot as a standard office building.
    a. 2
    b. 3
    c. 4
    d. 5

References

Pena, W. & Parshall, S. (2001) *Problem seeking. John Wiley & Sons, Inc.*

Princeton University Environmental Health and Safety. (2023, April). *Fume hood common misuses & limitations*. Princeton University. https://ehs.princeton.edu/laboratory-research/laboratory-safety/laboratory-equipment-and-engineering/fume-hoods/fume-hood limitations.

International Code Council, Inc. *(2021). 2021 International building code,* International Code Council, Inc.

National Fire Protection Association. (2019). 2019 NFPA 45 standard on fire protection for laboratories using chemicals. National Fire Protection Association.

Watch, D. (2016). *Trends in lab design.* Whole Building Design Guide. https://www.wbdg.org/resources/trends-lab-design.

Brader, B. & Bartlett, C. (2023, April). *Top 10 tips for successful lab design.* Clark Nexsen. https://www.clarknexsen.com/blog-top-10-tips-successful-lab-design.

U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, & National Institutes of Health (2009). *Biosafety in microbiological and biomedical laboratories 5th edition.* HHS Publication No. (CDC) 21-1112.

Department of Justice *(2010) 2010 ADA standards for accessible design.* Department of Justice.

Making Sense of Laboratory Fire Codes by Richard P. Palluzi, P.E., American Institute of Chemical Engineers, www.aiche.org/cep July 2017.

Izbicki, T. (2009). *Basics of NFPA 45 – Standard on fire protection for laboratories using chemicals.* Rolf Jensen & Associates, Inc.

Tradeline (2017). *Tradeline fundamentals of planning and design of university labs and MEP systems.* Tradeline.

Wilhelms, P. (2021) Five Considerations for the new lab of the future. Gensler. http://www.gensler.com/blog/five-considerations-for-the=new-lab-of-the-future.

Westlab (2019). *5 Key Considerations for a Great Laboratory Design.* www.westlab.com.

Parkin Architects Ltd (2021). *8 Considerations for a modern laboratory design.* www.parkin.ca/blog/8-considerations-for-modern-laboratory-design.

USA Lab (2019). *9 Essential tips for a successful laboratory design.* www.usalab.com/blog/9-essential-tips-for-a -successful-laboratory-design.

Oakland University (2023) *Augmented Reality Center.* https://oakland.edu/secs/labs-and-centers/augmented-reality-center.

Stanford University Environmental Health & Safety (2022). Laboratory standard & design guidelines. Stanford University. https://ehs.stanford.edu/manual/laboratory-standard-design-guidelines.

Antec Controls (2023) *Design considerations – laboratory*. Buckley Associates. https://buckleyonline.com/wp-content/uploads/2022/10/Antec-Design-Considerations-Laboratory-Fundamentals-v1-1.pdf

Liescheidt, S. (2021). Design considerations for school-based chemistry laboratories. Engineered Systems Magazine. https://www.esmagazine.com/articles/101354-design-considerations-for-school-based-chemistry-laboratories.

HMC Architects (2019). *Dry and Wet Laboratory Design on College Campuses.* HMC Architects. https://hmcarchitects.com/news/dry-and-wet-laboratory-design-on-college-campuses-2019-05-08.

Ohio State University (2023). *Considerations for Laboratory Design.* Ohio State University. https://ehs.osu.edu/sites/default/files/considerations_for_laboratory_design.pdf.

AIS Life Sciences (2022). *How laboratory design must account for labs of the future.* AIS Life Sciences. https://his-lifesciences.com/insights/labs-of-the-future-and-their-design.

DiBerardinis, L. (2016, March). Impact of lab design on safety, health, and productivity. Medical Lab Management.

AIS Life Sciences (2022, May 30). *Laboratory design to improve your employee experience.* AIS Life Sciences. https://ais-lifesciences.com/insights/laboratory-design-to-improve-your-employee-experience.

Texas Tech University Environmental Health and Safety *(2023). Laboratory Safety Manual.* Texas Tech University Environmental Health and Safety.

AIS Life Sciences (2022). Supporting mental health in the laboratory workplace with design. AIS Life Sciences. https://www.ais-interiors.com/insights/supporting-mental-health-in-the-workplace-with-design.

Biolife Solutions (2020, June 30). *Sustainable Laboratory Design Trends and Considerations.* Biolife Solutions. www.biolifesolutions.com/blog/ult-storage/sustainable-laboratory-design-trends-and-considerations.

University of Arkansas (2020, September). *New labcoat dispensing system helps keep researchers safer.* University of Arkansas News. https://news.uark.edu/articles/54511/new-lab-coat-dispensing-system-helps-keep-research-areas-safer.

Review Question Answers

1. Which of the following information is not important during the programming phase of the renovation of a 1,000 s.f. chemistry lab?
   a. The types and quantities of chemicals that will be used
   b. If it is a teaching lab or a research lab
   c. The budget for the project
   d. The owner's preferred color scheme

Correct answer is D. The owner's preferred color scheme (The owner's preferred color scheme is not important to the functionality of a lab or the schematic design.)

2. What is the maximum height for the top rim of an accessible sink?
   a. 32”
   b. 34”
   c. 36”
   d. 42”

The correct answer is B. A countertop that is not higher than thirty-four (34) inches,

3. Which BSL has the most stringent requirements?
   a. BSL-1
   b. BSL-2
   c. BSL-3
   d. BSL-4

The correct answer is D. BSL (Biosafety Level) refers to the ascending levels of containment for handling biological agents that pose different levels of risk to the workers and the environment. These levels build on each other as the containment needs increase.

16. What type of exhaust should be provided for the handling of harmful microorganisms?
    a. Snorkels
    b. Fume hoods
    c. Biological safety cabinets
    d. Gloveboxes

The correct answer is C. Work involving harmful microorganisms should be done in a biosafety cabinet rather than a chemical fume hood. A biosafety cabinet filters the potentially contaminated air through high efficiency particulate (HEPA) filters, and then vents that air back into the room.

17. When designing a flexible lab, which of the following elements are generally designed to be stationary?
    a. Workbenches and storage cabinets
    b. Storage cabinets and sinks
    c. Sinks and fume hoods
    d. Workbenches and fume hoods

Correct answer is C. (Workbenches and cabinets are designed to be mobile.)

18. Which of the following is not a budget consideration when designing a lab?
    a. Should the casework be fixed or mobile?
    b. Should you install epoxy flooring or vinyl flooring?
    c. Should you design for current needs or design for anticipated growth?
    d. Should you install a snorkel or gloveboxes to exhaust hazardous chemicals?

Correct answer is d. The type of exhaust is based on the chemicals and agents used – not the cost.

19. Well-designed fume hoods are capable of containing _____% of the contaminants released within them when used properly.
    a. 50
    b. 75
    c. 90
    d. 99.9999

    The correct answer is D. Well-designed fume hoods are capable of containing 99.9999% of the toxins released within them when used correctly.

8. If a combustible hazardous material has a flashpoint of 140°F, how would it be classified?
   a. Class II
   b. Class IIIA
   c. Class IIIB
   d. None of the above

The correct answer is B. (Go to the *Classes of Flammable and Combustible Liquids* table.)

9. Which type of exhaust system has the least initial cost for controlling odor and dust?
   a. Snorkels
   b. Ductless fume hood
   c. Ducted fume hood
   d. Biological safety cabinet

The correct answer is B. (Snorkels and biological safety cabinets should not primarily be used for controlling odors and dust. Ductless fume hoods cost less to install initially than ducted fume hoods.)

10. What is the preferred flooring for a BSL2 lab?
   a. Carpet
   b. LVT
   c. Epoxy with rubber base
   d. Epoxy with integral cove base

The correct answer is D. It is preferred because it is impervious and easiest to clean with the integral base.

11. Which of the following is NOT a result of the pandemic?
   a. Labs are shutting down because the pandemic proved that they aren't necessary.
   b. Automation of equipment has been increased.
   c. Outdoor meeting spaces are being formed.
   d. Office and support spaces are getting better ventilation

The correct answer is A. You can't perform the functions of the lab at home.

12. Which of the following increases human comfort and wellness in a new lab building?
   a. Natural light
   b. Access to green space
   c. Water features
   d. All of the above

The correct answer is D. (Research has shown that all items can increase wellbeing.)

13. Which design trend increases collaboration and innovation?
   a. Windows between the corridors and labs
   b. Alcoves with furniture for impromptu meetings
   c. Coffee shop in the lobby
   d. All of the above

The correct answer is D. (All of the items listed increase the number of chance interactions which leads to increased collaboration and a higher level of innovation.)

14. Which of the following methods can offset the effects of the high amount of energy and water

used in lab buildings?

a. Passive energy harvesting
b. Chilled beams
c. Heat wheels
d. All of the above

The correct answer is D. (Research has shown that all items can increase wellbeing.)

15. Typical lab buildings use ___ times as much energy and water per square foot as a standard office building.
    a. 2
    b. 3
    c. 4
    d. 5

The correct answer if D. Labs use 5 times as much energy and water per square foot due to the number of containment and exhaust devices, heat-generating equipment, 24-hr access, and redundant backup systems.