Division of Technical Resources
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The National Institutes of Health
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News to Use
Design Requirements Manual
The formulae $\frac{\partial \rho u_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_j u_i)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial u_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ for building $\frac{\partial}{\partial x_j}(\rho\overline{u_i}\overline{u_j})=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial \overline{u_i}}{\partial x_j}-\rho\overline{u_i'u_j'}\right)+g_i(\rho-\rho_0)$ state of the art $\frac{\partial}{\partial x_i}(\rho\overline{u_i}\overline{H})=\frac{\partial}{\partial x_i}\left(\lambda\frac{\partial \overline{T}}{\partial x_i}-\rho\overline{u_i'H'}\right)$ biomedical research facilities.

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Building Automation Systems – Part I Common Lab Room Requirements

Laboratories are designed with BAS systems to provide both temperature and pressurization control. If the laboratory is used for toxic chemicals and fumes, the laboratory HVAC system should provide negative pressurization to prohibit chemicals from migrating to other areas; if the laboratory is used for clean room applications, the laboratory HVAC system should provide positive pressurization to prevent contaminants from being drawn into the room. In any case, opening and closing of the doors shall not be impacted by airflow control. Individual laboratory humidity control is optional and shall only be done where required.

Generally, each lab zone shall have pressure independent terminal boxes on supply and exhaust, so that a volumetric flow rate set point of supply and exhaust into and out of the laboratory shall be automatically maintained regardless of fluctuations in static pressure. The pressure independent terminal box control damper is controlled to achieve a set point flow rate. The set point flow rate will be automatically varied between a minimum and maximum as necessary to meet the airflow demand of the room.

Laboratories shall have pressure or directional airflow controlled zones. On existing constant volume systems where installation of pressure independent terminals is not practical, and only with permission of the Project Officer, laboratory pressurization may be accomplished by balancing.

For Variable Airflow Volume (VAV) systems, laboratory zones shall be actively controlled by "flow tracking", i.e. maintaining an offset between the total supply and exhaust flow to the room. On zones that are required to be negative, the supply flow shall track the exhaust flow. On zones required to be positive, the exhaust shall track the supply.

If airflow is not being sensed directly, as in the application of a metering venturi valve, where the flow is being inferred from valve position, a pressure sensor shall be provided on both supply and exhaust systems that alarms when air pressure across the valve is not great enough to maintain the valve in appropriate range. For non-containment systems, if the lead system is in alarm for 2 minutes (enough time for an initial attempt at resetting set points) the system shall be put into a "Distress Mode" such that all pressure zone control set points are reduced to redistribute the lack of capacity in a prioritized fashion. Distress mode shall be alarmed and manually reset.

When less than 100% redundancy is provided in either a failure mode or an emergency power mode, and the pressure is controlled at the zone level, prioritized reset of the terminal flow set points is required to maintain the required room pressurization. The A/E shall dictate the priorities. Controls for laboratories shall be fed from emergency power.

Monitoring of space pressure with local indication is only required when the potential threat to human wellbeing or the research program from airborne contamination is significant and is required by the BMBL for BSL3 and ABSL3 facilities. This shall be discussed with the Project Officer, DOHS and the researcher to establish this need.

When the laboratory contains VAV fume hoods, the Controls Contractor shall integrate the fume hood controller with the room temperature and airflow controller. In this case, BAS controls the room pressurization and temperature requires pressure independent terminal boxes on the fume hood exhaust, general exhaust and the supply air.

The control strategy below describes these needs:
Room temperature shall be maintained by increasing the total zone exhaust airflow set point on a rise in temperature and by decreasing its set point on a fall in temperature (the minimum zone flow set point shall be limited to that required for air exchange). Room temperature shall also be maintained by modulating the reheat coil to maintain the heating set point.

Room pressurization shall be maintained by varying the supply airflow set point to track the total zone exhaust air being measured (hood flow plus general exhaust as applicable). Exhaust air through the fume hood shall be modulated to maintain an airflow that is required to maintain a face velocity set point, which is determined by the sash position. Fume hood controller shall maintain accurate control of average face velocity as fume hood sash is raised or lowered, or moved horizontally. Fume hood airflow controller shall calculate average face velocity from measured exhaust airflow and hood open face area. This face velocity is then compared to the set point to calculate required exhaust flow. The general exhaust airflow set point shall vary to maintain the total zone exhaust flow when the hood flow is less than that required for the cooling loop. All box dampers shall modulate to maintain the established flow set point.

A fume hood monitor shall be provided to receive the sash sensor output and an exhaust airflow control signal for the appropriate airflow control device. All fumes hoods require a local audible and visual alarm device, capable of detecting a drop or rise in airflow.

This application can be adapted for multiple supply or exhaust flow scenarios, or multiple fume hood sash panels.

In the VAV fume hood laboratory, the controller, terminal and all devices shall be laboratory grade that can act with the speed of response required to meet the requirements of the NIH fume hood testing protocol. This will require fast acting actuators and require fast responding controllers commensurate with laboratory grade control systems, as the speed of the supply and exhaust dampers directly affects temporary losses of pressurization. Conventional VAV terminals may be used for supply and general exhaust provided they are fitted with fast acting actuators.

Lab BAS manufacturer shall set up airflows in cooperation with TAB contractor. System startup and commissioning test shall be provided by factory authorized representatives. Please refer to NIH Specification Sections 15991 and 15992 for the details of the fume hood testing procedures.

Next month's article will discuss BAS requirements on BSL3 and ABSL3.

Further details on this month's topic are available on the DRM website
Design Policies and Guidelines
DRM Chapter 7, Section 7-3-D

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Building Automation Systems – Part II
BSL3, Animal Holding Room and ABSL3 Requirements

Level 3 Biological Safety Laboratories (BSL3) and Animal Biological Safety Laboratories (ABSL3) facilities are critical zones designed with robust directional airflow controls and pressurization monitoring systems. The control sequence and actual responses of all drives, sensors, fans, dampers and damper actuators shall be carefully examined, implemented and maintained at all times.

The following summarizes the Building Automation Systems (BAS) requirements generally implemented where applicable:

BAS components shall be selected and tested so that in any realistic failure scenario (power failures, single or multiple component failures, maintenance functions, etc.), the airflow will not be reversed; automatic dampers shall fail in safe positions; the supply air flow rate will decrease more quickly than the exhaust for negative containment spaces or vice versa for positive spaces.

Differential pressure monitors on critical containment zones shall be provided to indicate the room differential pressure (visual readout) and shall alarm when the pressure goes beyond adjustable thresholds and time durations established in concert with the Division of Occupational Health and Safety (DOHS) and the researcher.

Airflow tracking control shall maintain differential pressures of -12.5 pa (-0.05 inch of water) and -25 pa (-0.1 inch of water) between adjacent spaces. There shall never be a condition in which the control system goes outside this range for more than two minutes and directional airflow must be sustained by drawing air into the laboratory from "clean" areas toward 'potentially contaminated areas'. Additionally, a visual strobe shall alarm whenever any given space pressure becomes the reverse of its intended pressure for more than 20 seconds (i.e., when a negative pressure space becomes positive) or whenever the HVAC system fails. The laboratory shall be designed such that under failure conditions the airflow will not be reversed.

Air valve damper actuators shall be 'fast –acting' able to stroke the dampers within 2 seconds. Damper fail positions shall be selected to fail in the direction that would maintain pressurization. Fail in last position actuators shall only be used with specific permission. If a BSL3 facility requires multiple levels of room pressurization, digital differential pressure monitors shall be provided for each pressure controlled zone and shall monitor pressure between each zone and its adjacent reference zone. Pressures shall be maintained to ensure proper directional airflow between zones.

All controllers in a BSL3 lab area shall be provided with stand-alone capability at the suite level. The A/E shall clearly indicate both tracking relationships between airflow terminals and clearly indicate the bio-containment boundaries of a suite that shall be controlled by the same controller. The A/E shall work with the researcher to analyze the potential for loss of containment due to a controller failure or a controller LAN communication failure and design the controller configuration to minimize risk. Fail positions of the air valves shall be such that containment shall be maintained in the event of failures.

In BSL3 spaces, as the spaces are constructed "tight" to have minimal leakage, a cross-limiting loop shall be provided (the control sequence shall automatically reset the flow rate set point in the lead terminal box upon detection of excessive flow differential) to restrict the leading system from exceeding the lagging system by a specified value which shall be set to prohibit excessive door opening forces. As an example, if the normal offset is to have the general exhaust volume 150 cfm higher than the supply, another control loop shall restrict the general exhaust flow to no more than 300 cfm above the supply. Values shall be set such that the control loops do not interact under normal operation. Cross limiting does not apply to chemical fume hoods, biosafety cabinets, canopy hoods, or other safety equipment.

Controllers monitoring and adjusting the HVAC in BSL3 areas shall be primary controllers. Zone terminal unit controllers shall be on uninterruptible and emergency power so they can continue to control through power interruptions. Controllers shall have the capability to automatically restore their volatile memory upon loss of current.

Use a hard-wired interlock between supply controller and exhaust controller to provide supply and exhaust system status so that the lagging system can confirm operation of the leading system in the absence of the controller LAN communication. Where multiple controllers are controlling the exhaust system, status outputs shall be wired in parallel.

Where fireman's override controls are used, the A/E shall consult with the Division of the Fire Marshal (DFM) to determine the damper positions when the override mode is activated. They shall continue normal operating positions, but this shall be evaluated on a case by case basis.

<u>Animal Holding Rooms and ABSL3:</u>
Animal care shall always take precedence over system component protection. Animal holding rooms shall be controlled to temperature, humidity, airflow on a room by room basis. The control strategies are similar to those for the lab BAS control requirements.

The monitored points and hardware requirements associated with the zone (for zone related equipment requirements, see the applicable equipment) shall be as follows:

- Space Temperature (high accuracy and water proof sensor).
- Space Differential Pressure with local indication (where differential pressure is monitored).
- Space Humidity (+/-5% of set point when humidifier is used).
- Supply Air Humidity.
- Supply Air Humidity for High Limit (if not done with a local limit).
- Air Change Calculation either via terminal flow sensors or flow measuring stations.
- Light level monitoring shall be considered but may be part of a separate system as long as the required Association for Assessment and Accreditation of Laboratory Animal Care (AAALAC) data is stored.
- Supply/exhaust velocity (total/static differential) pressure.

Where Animal Holding Rooms are classified as ABSL3, requirements of BSL3 laboratories apply.

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Facility Design Criteria for Electron Microscopes – Part I

Electron microscopes (EM) use a beam of electrons to illuminate a specimen and produce a magnified image and can currently achieve magnifications of up to about 10,000,000X. Transmission electron microscopes (TEM) and scanning electron microscope (SEM) are high resolution instruments that are extremely sensitive to environmental instabilities such as *temperature, vibration, acoustic noise, pressure and magnetic fields*. Slight changes in any one of these parameters can cause distortion in the microscopic image. These and other high resolution instruments are sensitive to very low frequency noise sources.

General Design Criteria:

In designing rooms for high resolution equipment, it is important to ensure reliability and repeatability in the experimental results. To achieve optimal instrument performance, environmental instability should be reduced to the greatest degree possible. It is important to know the sensitivity of the instrument to be housed in the facility. The room housing a high resolution instrument should be considered an extension of the instrument.

High resolution equipment facilities (for TEM, SEM and other EMs) should meet as many of the following criteria as possible:

- The environmental control system shall have N+1 redundancy on ALL major components to keep the environmental chamber at constant temperature, pressure and humidity. The Control system shall utilize a full proportional-integral derivative (PID) controller. PID controller must be tuned using numerical method such as simplified first order plus dead time (FOPDT) process models.
- Located far away from roads, parking lots, elevators, and air handling equipment to minimize ground-borne vibrations from automobile and railway traffic, construction equipment, blowers and pumps, etc.
- Room should ideally be remote from corridors to avoid foot fall and moving cart vibrations.
- Isolated structurally from the main building to the greatest extent possible to mitigate the propagation of transient vibrations.
- Provided with restricted access.
- Ideally located below ground to facilitate constant temperature and be equipped with an adjacent control room that houses much of the electronic instrumentation.
- Air handling designed to prevent building air from blowing directly on equipment.
- Carefully regulated temperature and humidity control.
- Air that is typically filtered to reduce particle concentrations by roughly a factor of 10 below that of air circulating throughout the building. This should be verified based on research protocols.
- Far removed from high-voltage transformers and high-current electrical power lines.
- Independent and distributed, quiet electrical grounds should be available throughout the lab. Any required 110-V power lines should be filtered, regulated, and distributed by twisted wires to reduce stray magnetic fields.
- Minimize use of discharge lighting and ballasts.
- Use of electromagnetic shielding or a cancelling system to reduce the influence of outside electromagnetic interference (EMI).
- Sound-absorbent walls, ceilings, and floors which reduce background acoustic noise to a minimum and which are appropriate for clean environments.

Specific Design criteria:

Electromagnetic Fields - Keep Electromagnetic fields to less than 0.1 mG RMS (root mean square).

EMI can cause beam deflections in both the scanning system and the spectrometer.

Sources of electromagnetic fields from inside the room:

- Small pieces of metal moving near the equipment (such as the steel wheels on a chair).
  - Consider the use of plastic or all wood furniture inside the room.
- Electrical distribution and equipment.
  - Careful design of power routing and isolation of transformers and electric motors, background fields will help in reducing electromagnetic fields inside the room.
  - In a retrofit, overhaul existing wiring and install dedicated supplies for the microscope.
  - Route power conduits as far as possible from the microscope column.
  - The AC fields (mostly from computer monitors) should be 1 milligauss or less. Shielding for top performance, high resolution spectrometers and microscopes often specify ~ 0.2 milligauss (20 nT) p-pin x,y and z direction.
- Place monitors away from the column.
- Consider field cancellation systems at the specimen, gun, viewing chamber.
- Black and white TV monitors and computer monitors used on older model EM scopes.
  - LCD monitors are recommended.
  - Magnetic shielding can be used to provide a low reluctance path for external fields. The shielding has to close the instrument on all sides.
- Sources of electromagnetic fields from outside the room.
- Movement in a corridor, elevators or escalators near the equipment room.
- Roads, auto traffic and railroads.
- Loading dock, machine shop or room with cryo-pumps.

Details on Temperature and Humidity Control, Airflow across the column, Control of air pressure changes, Vibration Considerations, Acoustic Noise, Room Layout and Architectural Features will be discussed in next month's News to Use.

Further details on this month's topic are available on the DRM website
http://orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManualPDF.aspx
DRM Appendix J

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Facility Design Criteria for Electron Microscopes – Part II

March News to Use provided general design criteria and specific criteria for Electron Microscopes. This News to Use will provide specific criteria for temperature and humidity control, airflow across the column, control of air pressure changes, vibration considerations and acoustic noise.

Temperature and Humidity Control and Airflow across the Column

- Keep temperature changes to less than 0.1 degree Celsius per hour.
- Keep airflow across the column to less than 20 feet per minute. The airflow across the column may vary depending on the type and sensitivity of the equipment. Perform a risk assessment and set the airflow rate based on the results.
- A rough estimate of the heat output of a microscope (power supply and electronics rack) is 5kW. Confirm the thermal load from the vendor before the design.
  - Separate (and cool independently of the column and microscope) cooling for power supply and electronics racks.
  - Construct a shelter surrounding three sides of the column to prevent drafts blowing across the column.
  - Wrap column in bubble wrap or neoprene to dampen thermal fluctuations.
  - Radiant cooling system to control temperature is recommended and is an inexpensive retrofit used in conjunction with a forced air A/C system to control humidity.
  - To retrofit a forced air cooling system:
    - Add a reheat coil with feedback from the thermo-coupler near the column to reduce temperature fluctuations.
    - Place the inlets away from the column to avoid unacceptable currents.
    - Diffuse the air flow by installing a perforated ceiling tile with hundreds of small holes across the tile (but with none directly above the column) and arrange tiles to produce laminar flow.
    - A less expensive solution is to add a duct sock that is tightly sealed to the air inlet.
    - Minimize the cycling of cooling.
    - Minimize air supply to the instrument room to avoid sudden fluctuations in temperature.
    - Use the most accurate temperature probes.

Note that modern electron microscopes except monitors are usually continuously powered to maintain the stability and alignments. Monitors are routinely powered off (or set to energy saving mode) unless they have been replaced with the cooler flat-screen models.

Control of Air Pressure Changes

Pressure changes can cause blurring or deflection depending on the instrument. Air pressure changes of 1 Pa can result in stage deflection of about 0.1nm. Barometric pressure changes due to weather or opening an outside door in the building can affect the microscope room pressure.

To maintain pressure stability, recommend air pressure changes to less than a few Pascal per minute.

Vibration Considerations

Vibrations in a floor supporting the microscope may be caused by traffic on roads, rails or nearby machinery or movement of the building itself.

- The vibration criterion (VC) will be based on VC-D with the maximum vibration of 6 micrometers/sec, RMS. as measured in one-third octave bands of frequency over the frequency range 8 to 100 Hz.
- In order to reduce vibration to a minimum, support sensitive equipment on an isolated high mass platform designed to have a resonant frequency far below any internal resonance characteristics of the equipment itself.
- Surrounding background vibrational noise, or the "natural frequency" of a facility, should lie well above the resonance frequency of the high mass platform.
- Recommend the installation of the microscope on an isolated high-mass concrete slab on bedrock or appropriate engineered fill, with a gap between the concrete slab and the surrounding structure. The gap may be filled with a closed cell neoprene rubber gasket which does not transmit vibrations.
- The walls should be isolated from roof and the floor slab.

Acoustic Noise

In order to reduce the entrance of noise and to dampen noise in the room recommend the following:

- Achieve Noise Criteria NC-35 rating;
- Remove noisy microscope equipment (such as pumps, power racks, and compressors) to a different room or to a dedicated room;
- Another option for noise reduction is to install acoustically "dead" walls, which may be achieved through curtains or cloth covered fiberglass sound absorbent tiles with a sound absorbent factor of 1.15.

Room Layout and Architectural Features

High resolution instrument room layout will vary depending on the type and sensitivity of equipment specified and site constraints.
The electron microscope suite should include at a minimum:

- Separate room for heat, vibration or noise generating equipment associated with the electron microscope.
- Vibration isolation slab on grade for electron microscope.
- Appropriate shielding. Electromagnetic (EM) interference cancellation may require EM cancelling systems or shielding depending on the requirements of the microscope and building conditions.
- Dual pane windows for better sound isolation.
- Physical separation from busy corridors and other sound and vibration generating areas.

Other systems to consider include: Cooling Water (supply and return); House Vacuum; Dry N2 gas; Fire Alarms; Fire Sprinklers; Emergency Light; Oxygen Sensor; Telephone; Internet; and Instrument (ground) Shielding.

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Clearance for Equipment Access and Service

When designing a laboratory, an important aspect that should not be overlooked is clearance for the servicing of equipment. Laboratory equipment can be complex and sensitive, and require regular service, including:

- Calibration
- Filter changes
- Scheduled maintenance
- Repairs
- Upgrades

Proper planning is required to provide service personnel with sufficient access to internal components to perform the required service quickly. Challenges associated with equipment service in laboratories include:

- Service activities may be disruptive to laboratory operations, particularly if adequate service clearances are not provided,
- requiring things to be moved to create clearance.
- Service activities may require a lab to be recertified if SOPs are violated.
- Equipment, equipment components or tools may have to be
- cleaned or specially prepared before entering the laboratory, and decontaminated before leaving.
- Service personnel may have to gown up or wear personal protective equipment (PPE) and follow lab protocols.

Laboratory equipment can be categorized as movable, fixed-in-place, or building infrastructure. Each category has its own requirements.

Movable Equipment

Movable equipment includes both small benchtop items and large floor mounted items, including refrigerators, freezers, centrifuges and incubators. Although they are movable, service is usually performed in the laboratory.

Locating equipment in a common equipment room or area, even if within the lab, can isolate service activities from more sensitive laboratory operations.

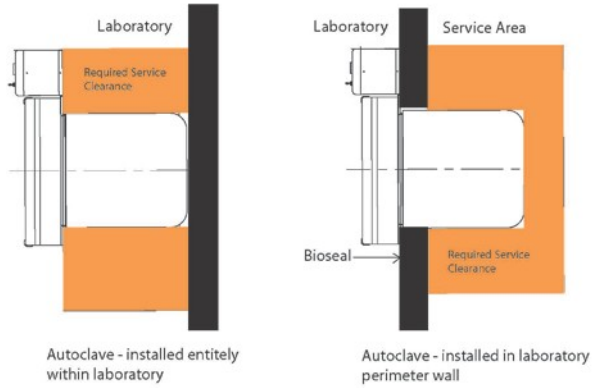
Most movable equipment serviceable components are housed within a cover that is wholly or partially removable for access. Clearance must be provided to fully open or remove the cover and for service personal to get in position to perform the required work. Most equipment is located against a wall, and service access can be from the front, sides or top. Some equipment, including refrigerators, must be pulled away from the wall. Some equipment, including robotic devices, must be located away from the wall to provide 360 degree service access.

Fixed-in-place Equipment

Fixed-in-place equipment includes larger items that are hard-connected to utilities and often permanently secured to the floor or walls. Items include fume hoods, large autoclaves and imaging equipment. Fixed-in-place equipment is often located in vivariums, containment labs and other spaces not conducive to service activities, but by its nature it must be serviced in-place.

It is ideal to locate the equipment so that items to be service can be accessed from areas outside of the lab (see Plans of autoclave installation configurations). It is often possible to recess equipment into a wall that forms the perimeter of the lab, allowing access to service personnel from adjacent areas without having to enter the lab. Autoclaves, for example, are often equipped with a bioseal that allows access to the chamber and controls from a containment lab, and concurrent access to mechanical and electrical components by service personnel from outside of the lab.

For equipment located wholly within a lab, service access should be provided so that service can be completed quickly and efficiently, without having to move adjacent items or otherwise disrupt lab activities. Regardless of equipment configuration, it is ideal to locate ancillary items that may require service (valves and dampers, for example) outside of the lab.



Plans of autoclave installation configurations

Building Infrastructure Equipment

Building infrastructure equipment is constructed on-site, and is integral with the building. Items include systems for pure water, animal watering, specialty ventilation or exhaust and piped utility services. These systems should be designed to locate valves, filters and other components requiring regular service outside of the lab. Ideal locations are in mechanical rooms, accessible chases or interstitial spaces. Less ideal locations are in accessible ceilings above corridors, office and other non-lab spaces.

A related issue is the engineering and utility systems that serve a laboratory, including heating, ventilation and air conditioning (HVAC) systems. These systems also require access for regular service and maintenance. For these systems there are a number of items to consider, including:

- Limiting the need for service personnel to enter the laboratory. This is especially important for containment labs, vivariums, clean rooms and other facilities with limited access or security requirements. In these cases, valves, filters, VAV boxes and other items needing service should be located in mechanical rooms or interstitial spaces accessed from outside of the laboratory.
- The mechanical rooms should be designed with adequate clearance to replace the largest piece of equipment. Aisle and door widths, turning radiuses, ceiling heights and elevator capacities in the equipment rigging path should all be considered.
- For interstitial floors and mechanical mezzanines, duct and piping layouts have to be carefully planned to ensure adequate ceiling height for safe and efficient working conditions. 3D visualization tools, including Revit, can be very beneficial.

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DRM Chapter 4, Section 4-5 Casework and Equipment

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Wall Construction in Vivariums

Vivarium walls have extremely stringent performance requirements. The Guide for the Care and Use of Laboratory Animals requires walls to be "*…smooth, moisture resistant, nonabsorbent and resistant to damage from impact*". The DRM requires that all laboratory walls be "*…capable of withstanding washing with strong detergents…*", and that vivarium walls specifically be "*…constructed of concrete, concrete block, or surfaced with a heavy duty, impenetrable veneer…*".

The performance of vivarium walls is crucial due to a number of factors:

1. Durability: Vivariums are subject to extreme wear and tear, including impacts, pressure washing and strong detergents.
2. Cost: Vivariums are very expensive to build and to operate. Delays during construction and downtime after completion are to be avoided.
3. Criticality: Vivarium operations are critical to research programs, and once in operation should not be disrupted for repair and maintenance.

A number of wall construction systems have met these requirements, and their selection should be based on the parameters and conditions specific to the project.

Base Walls

Base walls can be concrete (concrete masonry units (CMU) or formed concrete), or steel framing. Advantages and disadvantages include:

Concrete Advantages:

- Impact resistance. This is important in areas subject to heavy cart, cage and other wheeled traffic.
- Water resistance. This is important in areas that are subject to high humidity and wash downs.
- High mass: The high mass of concrete walls gives them good sound damping characteristics.

Concrete Disadvantages:

- Difficulty routing piping and conduit. Surface-mounted services are to be avoided, so services must be cast in concrete or routed through hollow CMU cores. This will negatively impact construction schedule and cost.
- Difficulty making modifications. Concrete and CMU, by its nature, is not easy to cut and patch, and modifications are costly and disruptive.

Steel Framing Advantages:

- Fast construction. Steel framing is a familiar and fast construction method. One advantage is the ability to route services through the walls. Vivarium-specific detailing is required, including the capping and sealing of hollow wall spaces
- Ease of modifications. Steel framed walls and components can be modified, patched and repaired more easily than concrete.

Steel Framing Disadvantages:

- Light weight. Steel framing is a relatively lightweight system, which is subject to impact damage. This can be mitigated by the use of heavier gauge framing and impact-resistant substrate and finishes.
- Water damage. Steel framing and substrate material is subject to corrosion, degradation and mold growth. This can be mitigated with proper material selection and detailing.
- Low mass. Low mass results in high sound transmission. This can be mitigated with sound insulation and detailing to add mass and break vibration paths.

Wall Finish

Of equal importance to the base wall system is the wall finish. Options include:

Concrete Wall Finishes: The typical finish is epoxy paint, which is a durable non-absorbent finish. The concrete or CMU surface must be smooth and free of pits and voids. For CMU, consideration should be given to smooth surfaces, radiused outside corners and flush joints. CMU must be finished with at least 2 coats of a high-quality block filler to provide a pinhole-free substrate for the paint. Before application, the painting contractor must check all environmental and physical conditions to ensure that the requirements of the paint are met. The base of the wall is detailed with coved bases integral with the floor, and wall protection rails are installed to protect the paint finish.

Steel Framing Wall Finishes: The typical substrates on a steel frame wall are gypsum wall board or cementitious hard board. Steel framing and substrate must be carefully detailed to provide a wall that will withstand the expected forces of impact and pressurization, be water resistant and vermin-proof. Standard gypsum board is not appropriate; the substrate must be a specialty high-impact and water resistant product.

The wall finish can be epoxy paint or a pre-manufactured sheet system (fiberglass reinforces polyester (FRP) or similar). Epoxy paint is similar to that described in Concrete Wall Finishes. Epoxy paint on steel frame walls can be installed with a fiberglass mat reinforcing layer to increase impact resistance. Sheet systems consist of pre-finished resilient sheets (typically 4' x 8' or 4' x 10' in size) which are adhered or mechanically fastened to the wall, with sealed perimeters and joints. Sheets are engineered to be durable and chemical resistant, and require no further finishing after installation. The base of the wall is detailed with coved bases integral with the floor, and wall protection rails are installed to protect the finish.

Further details on this month's topic are available on the DRM website
http://orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManualPDF.aspx
DRM Chapter 4, Section 4-3 Interior Architectural Elements

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Ceiling Options in Vivariums

Ceilings, like all other vivarium assemblies, have stringent performance requirements. The Guide for the Care and Use of Laboratory Animals requires that ceilings be *"…smooth, moisture resistant, non-absorbent and resistant to damage from impacts"* and *"…free of cracks, unsealed utility penetrations and imperfect junctions"*. The National Institutes of Health's Design Requirements Manual (DRM) requires that all laboratory finishes be *"…capable of withstanding washing with strong detergents…"*.

The performance of vivarium ceilings is crucial due to a number of factors:

1. Durability: Vivariums are subject to extreme wear and tear. Depending on the location, ceilings may be subject to extreme humidity, pressure washing with strong detergents and pressure differentials.
2. Cost: Vivariums are very expensive to build and to operate. Delays during construction and downtime after completion are to be avoided.
3. Criticality: Vivarium operations are critical to research programs. Ceilings failures, which may disrupt operations, are to be avoided.

Exposed-structure ceilings are generally not appropriate for vivariums, but can be used in limited applications if detailed to eliminate exposed ductwork, conduit and other items that could hinder cleaning or harbor pests. Most vivariums utilize one or a combination of suspended ceiling types. Regardless of the type of ceiling, utility systems should be carefully designed to limit the need to access above-ceiling devices within the vivarium perimeter. Suspended ceilings options include:

Acoustical Tile Ceilings

Acoustical tile ceilings offer the advantages of low cost and fast installation. Acoustical tile ceilings are also pre-finished, and provide unlimited above-ceiling access. Specialty systems are available with a number of features which are necessary for vivarium applications:

- Corrosion resistant suspension system and grids. This is necessary due to the high humidity and harsh cleaning compounds in many vivarium environments. All components, including anchors and connectors, must be of compatible, corrosion-resistant material, and designed for heavy ceiling tiles and room pressurization.
- Fiber reinforced polyester (FRP) ceiling tiles. Ceiling tiles have to be heavy-duty, moisture proof and non-sag.
- Continuous gaskets. Ceiling tiles and grid must have gaskets to provide a continuous seal. The gaskets must be compression-bulb type or otherwise appropriate for repeated re-sealing, and must be chemical and moisture resistant. Gaskets are also required at lights, mechanical devices and all other ceiling-mounted items.
- Hold-down clips: Clips are required to hold down the ceiling tiles and compress the gaskets, ensuring that items are not dislodged and the ceiling maintains its integrity.

Acoustical tile ceilings have a number of disadvantages. If not carefully installed and maintained, gaskets and clips may not maintain the integrity of the ceiling seal. Pressure-washing and other maintenance activities can dislodge and damage tiles. For these reasons, acoustical tile ceilings are often not used in cage wash rooms, holding rooms, and other rooms subject to wash-down and high humidity.

Gypsum Board Ceilings

Gypsum board ceilings provide a smooth, monolithic, sealed surface. When finished with a high-quality epoxy paint, gypsum board can provide a durable, water-resistant assembly.

The suspension system, consisting of a grid of main- and cross-members suspended from the building's structure, must be corrosion resistant and designed for room pressurization. Standard gypsum wall board is not appropriate for vivarium applications, and a moisture-resistant, non-sag, impact-resistant board must be used. The finish of the gypsum board must be compatible with and meet the specifications of the epoxy paint to be applied. The epoxy paint is key to the integrity of the ceiling assembly, so the painting contractor must confirm that all conditions are acceptable prior to paint application.

Fiberglass Reinforced Polyester (FRP) Ceilings

FRP is a polymer and fiber composite material, usually available in 4' x 8' or 4' x 10' sheets. FRP systems consist of sheets, anchorages, sealants, battens and other accessories. An assembled system provides a pre-finished, durable, water resistant ceiling.

FRP systems require a suspension system similar to gypsum board ceilings. Some FRP systems are installed directly to the suspension system, and some are adhered or fastened to a gypsum board substrate. FRP panels must be installed following manufacturer's directions, using all required accessories and materials, to achieve a complete, warranted system.

For both FRP and gypsum board ceilings access must be provided for all above-ceiling items requiring maintenance. Access panels must be sealed or gasketed stainless steel. Lights, mechanical devices and all other ceiling penetrations must be sealed, per the DRM Sealant Table, to ensure the integrity of the ceiling seal.

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DRM Chapter 4, Section 4-4 Interior Finishes

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Floors in Vivariums

Vivarium floors, like all other vivarium assemblies, have stringent performance requirements. The Guide for the Care and Use of Laboratory Animals requires that floors be *"…moisture resistant, non-absorbent, impact resistant and relatively smooth…" "…have a minimal number of joints". The DRM requires that floors be "resistant to the adverse effects of disinfectants, high-temperature water, and detergent cleaning… continuous movement of cages and equipment… permits the easy wheeling of cages or other equipment through the animal facility".*

Due to the requirements for moisture resistance and disinfection, monolithic flooring is required in all areas within a vivarium perimeter. The tried-and-true flooring of choice is epoxy resin.

Alternatives to Epoxy

In area subject to more moderate wear (entry and administration, behavioral studies, surgery, imaging), seamless vinyl or seamless rubber terrazzo with integral coved base may be appropriate and should be considered as alternates to epoxy. Although less durable than epoxy, these floors have superior cushioning and acoustic properties, are less expensive to install, and are easier to repair. Standard Operating Procedures (SOPs) and the institutional experience of maintenance and animal care staff will determine whether these floors are appropriate.

Epoxy

The primary working area of a vivarium (holding rooms, cage wash, primary corridors, and procedure rooms), however, are subject to extreme abuse on a daily basis, including:

- Heavy wheeled traffic
- Impacts
- Harsh chemical cleaning
- Thermal shock from steam cleaning
- Pressure washing

For these conditions, the durability of epoxy is required. Although an ideal material with a long history of success, epoxy floors can fail if not detailed properly and installed under the right conditions. A key element for a successful installation is planning from early in the design phase:

Concrete Slab Design: Epoxy is chemically bond to the concrete, which makes it more durable than surface-applied sheet flooring like vinyl and rubber. However, if the bond is not strong delamination and failure can occur. One source of failure is vapor transmission through the slab. To reduce vapor transmission, the slab must be designed appropriately for the specific conditions, and typically includes a vapor barrier, a granular drainage layer and an underslab drainage system.

Installation of floor drains and sloped floors should be carefully considered, since they have major impact facility operations.

Drains and sloped floors (at 1/8" per foot) are generally appropriate for rooms with the most extensive use of water and subject to wash-down, like large animal holding rooms and cage wash areas. Drains and sloped floors are generally not used in corridors, small animal holding rooms and procedure rooms.

Slabs must be designed for high floor loading, which is in excess of standard laboratory floor loading.

Product Selection: Epoxy flooring systems are produced by many manufacturers, and vary in their composition and characteristics. It is important to identify a specific flooring system compatible with the intended use and conditions, and with a successful track record. Once identified, the selected system will be used as a basis for making decisions throughout the design process. Vivarium floors have many unusual conditions, including pits, trench drains, gratings, curbs and sloped floors, which must be finished in epoxy. It is ideal to use an epoxy manufacturer's tested and recommended details to ensure compatibility with their system. A manufacturer can also supply specification requirements for concrete (including chemical composition, pH, vapor transmission, moisture content) to ensure compatibility with their system

Mock-up: It is highly recommended that an on-site mock-up be used as a basis for performance for the actual floor installation. The mock-up should be installed in close proximity to the actual installation, under conditions as close to the actual installation as possible. The mock-up should include as many typical conditions as possible (base and wall termination, inside and outside corners, floor drain, pit, curb, etc.). Upon completion, the mock-up should be tested for thickness, hardness and adhesion, and reviewed by the users and design team for color and slip-resistance. Upon acceptance, the mock-up should be retained and used as a reference basis for performance and acceptance.

Testing: It is imperative that the epoxy installer visit the site and test the concrete slab to confirm that conditions meet their requirements. The installer must be authorized by the manufacturer, and be a certified Society of Protective Coatings Application Specialist. Installation should not commence until all required conditions are met. The installer may have to pre-treat or prepare the slab.

Installation: Due to its critical nature, it is important that the installation of the epoxy floor is not rushed. As a finish trade, flooring installation should be as late as possible in the construction sequence to ensure that the floor is not damaged by subsequent activities. Installation should not begin until the HVAC system is running, the environment has stabilized and the concrete floor has cured and dried to within manufacturer's recommendations.

Post Installation: The epoxy should be given adequate time to cure under recommended conditions. When allowed, the floor should be covered and protected until occupancy. After occupancy it is important to follow manufacture's recommendations for maintenance and repair.

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Piping Insulation Systems

While piping insulation may seem routine, inadequate consideration can have significant impact on research facilities. Section 6-4 of the Design Requirements Manual provides basic requirements for these systems to be used along with the substantial detailed technical guidance that is readily available throughout the facilities design and construction industry.

Appropriately applied piping insulation systems serve a variety of critical functions including thermal control vital to energy savings and efficient operation, protections of building surfaces from condensation, mold and water damage; acoustical dampening, personnel protection associated with isolation from hot and cold surfaces, and in some cases can even be used to address unique considerations such as UV damage protection and as a means of achieving cleanable surfaces where piping materials are otherwise unsuitable.

Piping insulation systems are composed of the primary insulating material, external protective jacketing, and a variety of components as required to maintain the appropriate system continuity and durability (such as insulation jacketing, coverings for the various fittings and valves, fasteners, joint and end sealing systems, and insulation support inserts). All these components help protect the insulation from crushing and maintain its useful function.

Laboratory research facilities often have a myriad of specialty piping systems of various materials which can directly influence the insulation system selected. One of the most critical considerations is confirming compatibility of the insulation inclusive of its various components and installation methods with the actual material of the piping system or application itself. Inadequate consideration can lead to failure of piping systems. For example, many insulation formulations may contain chlorides (which can cause corrosive pitting and failure of stainless steels). Some jacketing materials may contain plasticizers or other incompatible components which can induce stress cracking or otherwise be detrimental to certain plastic piping systems. Some insulation systems (such as unjacketed calcium silicate and perlite materials) are unsuitable for research areas sensitive to dust. Special cleanliness characteristics and materials are required for food processing and clean room areas to protect from potential contamination and maintain suitable cleanliness.

Where insulation systems are utilized for control of condensation, care must be applied to ensure complete and thorough insulation results inclusive of sealing of joints and terminal ends. Hangers and supports are applied on the outside of insulation to prevent breach of the vapor barrier along with use of appropriate insulation inserts. Poorly applied insulation systems can sometimes be prone to a wicking effect and once insulation systems start to get wet (whether due to condensation, leakage, or an inadequately completed system repair) damage to large amounts of piping insulation beyond the initial insulation breach can occur resulting in trapped liquid under the insulation, an undesirable condition which compromises insulation effectiveness and could eventually result in piping failure.

The DRM also maintains specific requirements for application of insulation materials. As examples, the NIH requires storm drainage systems to be fully insulated as well as portions of drainage systems which carry cold waste to an appropriate point of dilution. Insulation which can contribute dust concerns is limited with regards to acceptable locations. In the case of rainwater drains, both vertical and horizontal storm lines are insulated. The cost of insulating the small amount of vertical piping associated with rainwater leaders is not offset by the potential damage that occurs to research facilities and their piping networks due to condensation of these systems, especially during periods of renovation to a lab or floor where environmental control may be reduced in part of a facility from normal operating conditions. Storm overflow systems (which do not normally carry water) do not require insulation on vertical sections. Condensation protection associated with inadequate design and insulation application should not be taken lightly. Drippage around drain bodies (whether roof drains or even floor drains receiving cold condensate) can be significant, contribute to mold, and could even incite a loss of research, especially where a lab is directly beneath the defective condition. Poor planning of piping installations (and especially condensate receiving drains serving mechanical equipment) can result in inadequate capability to properly insulate these drains as cast in floor slabs, resulting in on-going condensation problems. The DRM plumbing chapters provide further requirements to ensure drain bodies may be effectively insulated, and it is important requirements are properly coordinated.

A variety of valves and serviceable components are installed in laboratory piping systems and in many cases continuous insulation is required to maintain system effectiveness and energy efficiency. The use of removable insulation covers is required for large valves and specialties to facilitate routine maintenance access without damage to the insulation system. In all cases insulation systems must be selected appropriate to the piping system application, intended purpose, and installation environment; whether exposed to UV light, high humidity, or in a location of potential mechanical damage or impact. In the cases of external moisture, insulation jacketing systems must be provided with an approved, fully sealed jacket. Piping systems applied in areas where the insulation could be compressed (such as walkable areas) must be sufficiently strong to withstand compressive forces. Piping in exposed materials handling areas must be fitted with suitable stainless steel or aluminum jacketing to a distance of at least 8-feet above the floor. Piping insulation in mechanical rooms less than 8-feet above the floor and where otherwise required is provided with heavy PVC or suitable metal (aluminum or stainless steel) protective jacketing. Compatible insulation inserts are required at interface with pipe hangers and supports. Insulation systems must be appropriately durable and protected from normal wear and tear which includes provision of appropriate fitting covers. While direct bury of insulated systems are avoided at the NIH, the use of approved prefabricated leak-tight systems would be necessary where such installations cannot be avoided.

Piping insulation systems must be selected with appropriate fire hazard ratings which shall not exceed 25 for flame spread and 50 for smoke developed as per ASTM E84 or NFPA 255. All components used in conjunction with insulation systems must be appropriately resistant to mold and insects. Exposed insulation should be avoided in sterile spaces, as well as animal holding rooms and BSL-3 areas in as much as possible. Where not otherwise avoidable, such insulation must be readily cleanable and not harbor insects, moisture, or vermin. Thoughtful location of piping and equipment, along with proper rough-in placement can often minimize the need for such insulation. Where required, fully sealed, hard-jacket systems including pre-insulated piping components (typically with a hard plastic or stainless surface) are available, and requirements associated with these spaces are discussed in other chapters of the DRM.

Insulation is often required to provide freeze protection; however the design engineer must carefully consider whether insulation in itself is adequate for the proposed application, and also whether piping is acceptably located in the first place. Other sections of the DRM limit piping installations within exterior walls, recognizing insulation is not a substitute for a reliable heat source or other precautions for freeze protection. Regardless of the purpose of the piping insulation system, a thorough and professional application of the insulation system is critical to its success, and must be adequately specified to be in accordance with industry standards and all manufacturers' recommendations and reviewed during facility construction. Contractor requests for any deviations / substitutions should not be permitted without prior approval from DTR.

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DRM Chapter 6, Section 6-4 Thermal Insulation Systems

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NIH Fume Hood Testing Protocol

The National Institutes of Health (NIH) Fume Hood Testing Protocol is an enhanced testing procedure for testing fume hoods using ANSI/ASHRAE STD 110 as its baseline performance document.[1] ANSI/ASHRAE STD 110 does not make provision for related factors such as procedure being performed, internal obstructions and factors beyond basic performance of the hood itself. The standard does not provide 'pass/fail' criteria for the test—provides merely a method by which to conduct one. ANSI/ASHRAE STD 110 is meant as one tool in the evaluation of a fume hood, but not a final measure. The NIH Containment Fume Hood (CFH) Testing Protocol was created by Farhad Memarzadeh of the National Institutes of Health in 1997 and further revised by Memarzadeh and Brightbill in 1999 to address these and other deficiencies.[2] The protocol was developed using numerical and experimental testing methods for over 250 laboratory configurations. It features both static and dynamic test procedures that reflect actual exposure levels that workers may experience when using a CFH and it provides specific definitions, instrumentation requirements and pass/fail criteria for each test modification. Thousands of fume hoods have since been successfully tested using the NIH protocol.

Designers and engineers often assume that in complying with ANSI/ASHRAE 110 they are optimizing containment and accounting for the safety of the environment and the health of the workers. However, because a fume hood is a partial containment enclosure, it cannot provide absolute containment. Some level of leakage and exposure inevitably occurs during use. For a CFH acceptance to be based on achieving a minimum containment value by a standardized test protocol, a risk assessment to evaluate the fume hoods placement and working conditions when establishing the face velocity must be performed and tolerance limits defined in each set of circumstances. Once the CFH has been tested for containment, face velocity can be used as a presumptive measure of containment provided that no significant changes to the laboratory CFH supply air or exhaust air ventilation systems have occurred.

Unlike ANSI/ASHRAE STD 110, the NIH testing protocol has clear performance and prescriptive based pass/fail criteria for various parameters whose target values must meet prescribed acceptance levels for dynamic and static tests. The NIH "Static Testing" procedures account for a more cluttered hood, higher tracer gas (6 LPM) release rates and lower allowable measured leakage rates. The NIH "Dynamic Challenges" to the hood includes sash movements and subsequent Variable Air Volume (VAV) exhaust valve response, walk-byes and door movement. Additionally, it assesses turbulent intensity (TI), a much more proportional measurement than face velocity and a more representative parameter of containment effectiveness than those measured in the ANSI/ASHRAE 110 protocol. The NIH testing protocol assesses TI from face velocity for installed conditions. Contaminant leakage is observed from different positions within the hood, with a variety of sash opening settings, at different face velocities and with movement across the face of the hood with and without an operator. Further, it assesses quality of design, installation, and construction such as requiring mock-up testing prior to approval or Hood/Control system combination by an independent agency at the manufacturer's facility for "As Manufactured" (AM); performing most testing during final commissioning and assessing performance of at least 50% of units (100% of CFHs must be tested if the number of hoods is less than or equal to five) for "As Installed" (AI), and testing "As Used" (AU) conditions in which obstructions are present inside the hood and a simulated operator is present to measure the effects of disturbances during experimental setup. Other parameter performance requirements and measurements include:

a) Face Velocity Baseline (FVBL):.51 m/s ± .05m/s
b) Control Linearity (Cl expressed in %): < 2%
c) Time to Steady State$_{10}$ (TSS$_{10}$ expressed in seconds): < 2 sec.
d) Time to Steady State$_5$ (TSS$_5$ expressed in seconds): < 3 sec.
e) Face Velocity Overshoot/Maximum Deviation: < 15% which means at no point throughout the test shall a sample be recorded < 0.43 m/s or > 0.59 m/s
f) Response Time Constant (RTC expressed in seconds): < 0.5 Sec.
g) Steady State Deviation (SSD expressed in %): < 5% assessed using calculated face velocities
h) Controllability (expressed in mV/mm): > 12mV/25.4mm
i) Calculate the TI throughout each test
j) Correlate the TI to the "Box Leakage Factor"
k) For the VAV fume hoods, more details of Alternative Parameter Performance Requirements can be found in NIH Spec. 15992

All tests must be documented in a written report with graphics. On-site testing and off-site mock up to be performed per the NIH protocol are conducted independently of both the fume hood manufacturer and the fume hood control system manufacturer.

NIH Spec. 15991 & 15992 require that testing not start until testing, adjusting and balancing of the air and water systems, calibration and tuning of controls systems, off-site testing of fume hoods and commissioning are complete and the facility is ready for occupancy. Both testing protocols shall be conducted in accordance with ANSI/ASHRAE 110 - Method of Testing Performance of Laboratory Fume Hoods with modifications that constitute the NIH protocol requirements. Additional information regarding fume hood containment testing, room configuration, ventilation requirements etc. can be found in the NIH Design Requirements Manual.

References:

1. American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE*): Method of Testing Performance of Laboratory fume hoods* (Standard 110). Atlanta, Ga.: ASHRAE (1995).

2. Memarzadeh, F**.** *Methodology for Optimization of Laboratory Hood Containment.* Vol I and Vol II National Institutes of Health Bethesda, Md.(1996).

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http://orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManualPDF.aspx
DRM Chapter 6, Section 1-00 D.7.d - Fume Hoods
National Institutes of Health Specifications -http://orf.od.nih.gov/PoliciesAndGuidelines/Bioenvironmental/Pages/default.aspx

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Generator Physical Installation and Mechanical Requirements

Generators usually support critical electrical loads in many National Institutes of Health (NIH) facilities in case of loss of normal electrical power. Reliability of generator power source is crucial for supporting the NIH mission to health and research. As a result, generator design, installation, and operation must ensure a high degree of reliability and availability.

Generator installations shall meet NFPA 110: Standard for Emergency and Standby Power Systems and various provisions of the NIH Design Requirement Manual (DRM) and the following requirements:

- Locate generator where it easily accessible for service and future replacement.
- Provide at least 1.2 m (4 ft.) of clearance around the generator set and access for replacing the generator without moving the generator set accessories, such as a day tank.
- Locate generator away from high ambient temperatures. Provide protection from the weather and from vandalism and avoid structure-borne vibration.
- Locate generator close to the main normal power source.
- Location of the engine exhaust discharge shall be determined by wind wake and dispersion analysis.
- Locate generator where it will be acceptable to tolerate the noise generated from engine, radiator fan, and exhaust system.

Engine exhaust system shall not create excessive back pressure on the engine and shall not be connected to any other exhaust system serving other equipment. Engine exhaust piping shall comply with the following:

- Refer to the DRM Exhibit X6-3-A for requirements of the engine exhaust pipes.
- Exhaust pipes shall be freestanding, not supported by the engine or muffler.
- Pipes shall use vibration-proof flexible connectors and shall be guarded to prevent contact with personnel, and avoid personnel injuries and burns.
- Exhaust pipes shall be routed to avoid fire detection devices and automatic sprinkler heads.
- Engine exhaust shall be directed up to maximize sound attenuation.
- Exhaust pipes shall be vented to the atmosphere away from building doors, windows, and ventilation intake vents to avoid covering walls and windows with soot.
- Insulated thimble pipe fittings shall be used at the point where the exhaust pipe penetrates the exterior wall or roof.
- A hinged rain cap shall be provided on the vertical discharge.
- Horizontal exhaust pipes shall be pitched downward and away from the generator set. At the end of the horizontal run, a condensate drain trap with hose connection shall be provided. A drain valve shall be provided at the bottom of each vertical section of the exhaust piping.

The optimal generator location is outdoors in a sound-attenuated enclosure that provides 70 to 79 dB maximum noise level 6 m (20 ft.) from the enclosure at rated output, regardless of generator size. The generator exhaust silencer, or muffler, shall be rated for minimum residential use or quieter to achieve the required sound rating. Muffler shall be installed as close as possible to the generator.

For indoor generator installation, the following design requirements apply:

- Sound attenuated room shall be provided to suit the generator being installed and the surrounding occupancies.
- Include a ventilation system to remove heat and fumes dissipated by the engine, electrical generator, accessories, load bank and other equipment located in the room. A maximum 11°C (20°F) room temperature rise above ambient shall be utilized in designing the ventilation air system. The design shall take into account the additional cooling air if load bank is unit mounted.
- Air intake louvers to ventilate the generator room shall be sized to accommodate the amount of combustion air needed by the engine, the amount of cooling air that flows to the radiator and any other amount of air needed to ventilate the room.
- Air intake louvers shall require fast opening before pressurization of the intake plenum to avoid damage to louvers. The combustion and ventilation air intake shall be coordinated so that they do not draw in engine exhaust.
- The air for either cooling or combustion purposes shall be primary filtered as it enters the building from outside. The engine filter shall be considered a second and final filter for indoor units.

The paragraphs above only highlighted some of the important guidelines of the DRM. Refer to the DRM and NFPA 110 for additional requirements on generator installations. Most importantly, generator installations shall ensure a high degree of reliability and availability to support the vital NIH missions.

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The formulae $\frac{\partial \rho U_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho U_i U_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ for building $\frac{\partial}{\partial x_j}(\rho\overline{U_i U_j})=-\frac{\partial \overline{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial \overline{U_i}}{\partial x_j}-\rho\overline{u_i u_j}\right)+g_i(\rho-\rho_0)$ state of the art $\frac{\partial}{\partial x_i}(\rho\overline{U_i H})=\frac{\partial}{\partial x_i}\left(\lambda\frac{\partial \overline{T}}{\partial x_i}-\rho\overline{u_i h}\right)$ biomedical research facilities.

'Design Requirements Manual (DRM) News to Use' is a monthly ORF publication featuring salient technical information that should be applied to the design of NIH biomedical research laboratories and animal facilities. NIH Project Officers, A/E's and other consultants to the NIH, who develop intramural, extramural and American Recovery and Reinvestment Act (ARRA) projects will benefit from 'News to Use'.
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Generator Fuel Supply

Generators typically support critical electrical loads in many National Institutes of Health (NIH) facilities in case of loss of normal electrical power. Generator fuel supply reliability and security of installation are critical for supporting the NIH mission to health and research. Generators and fuel supply systems shall be located in a secured area to protect the installation. The fuel oil system shall be engineered and installed to industry standards. The design of the fuel supply and storage system shall comply with the following requirements:

- Locate the fuel oil supply tank as close as possible to the emergency generators.
- Supply the emergency generator with a safe and uninterrupted source of #2 fuel oil. Onsite fuel storage capacity shall be adequate for a minimum of 24 hours run time at 100% generator nameplate. For locations other than the NIH Bethesda campus, minimum fuel storage capacity of 48 hours run time at 100% generator nameplate load is recommended. Tank sizing calculation shall consider the duration of expected power outages versus the availability of fuel deliveries and the shelf life (The shelf life of #2 fuel oil is 1.5 to 2 years) of the fuel oil. Where fuel storage capacity is large or may be stored for prolonged periods, evaluate the need for a fuel polishing system.
- Emergency generator(s) fuel oil shall not be used for any other purpose and shall not be shared with any other equipment.
- Locate day tanks as close as practical to the generator's engine and locate at an elevation where the highest fuel level in the day tank is lower than the diesel fuel injectors. Vent day tanks installed indoors to the outside.
- The fuel supply line from the storage tank to the day tank shall have redundant automatic transfer pump. The overflow line from the engine shall be returned to the storage tank, not the day tank. In gravity situations where the main fuel tank is higher than the generator, a "reverse day tank" (return storage tank) shall pump excess fuel back to the main tank. Fuel lines shall not be routed on the surface of the floor or anywhere subject to wear or physical damage.
- Underground fuel oil piping shall be double wall fiberglass and shall be provided with a leak detection and monitoring system. Above ground fuel oil lines shall be black steel. Compatible metal fuel oil pipes and fittings shall be used to avoid electrolysis.
- Size fuel oil supply pipes and pumps to handle a fuel oil flow rate three times greater than the full-load fuel oil consumption rate specified by the generator manufacturer. In multiple day tanks applications, size the main fuel oil pump system for three times the total fuel oil flow with all generators running at full load simultaneously. Size fuel oil return pipes for twice the total fuel oil flow rate. Pipe engine return-fuel oil back to the fuel oil supply tank.
- Provide an electric solenoid shutoff valve for fuel oil supply line to each generator. Connect the solenoid valve to the engine starter circuit to open the valve prior to energizing the generator.
- Provide a flexible code approved tubing between the engine and the fuel supply line to isolate vibration from the generator's engine.
- Provide Building Automation System (BAS) monitoring of main storage and generator day tank high level and critical high level alarms as well as fuel tank rupture alarm.
- The design specifications of the fuel oil system shall include all tank specialties such as fuel level alarms, filling accessories, control devices and all monitoring and testing devices.
- Fill piping shall be a minimum 2 inches in diameter, shall terminate above grade and shall be designed to minimize spilling when the filling hose is disconnected.
- For fill pipes serving tanks larger than 660 Gallons, an overflow/spill containment device shall be provided pipes.
- Fuel tanks shall be adequately vented to prevent pressurization.

The above mentioned paragraphs highlighted some of the important guidelines of the DRM regarding generator fuel supply systems. Refer to the DRM, NFPA 110, IMC and NFPA 37 for additional requirements on generator fuel systems installations. As the reliability of generator fuel supply is critical, installation of the fuel systems must comply with above mentioned guidelines and ensure ease of maintenance of all fuel system components including fuel quality check.