The following Design Policies and Guidelines shall apply to all systems within the Mechanical Engineering discipline. The purpose is to provide uniformity of design based on the established NIH Architectural and Engineering Design Policy and Guidelines. Systems may include heating, ventilation, and air-conditioning (HVAC), plumbing, piping, utility distribution, and automatic controls.

D.1Reference Design and Safety Guidelines for the HVAC Designer

The NIH is a progressive and dynamic biomedical research institution where state-of-the-art medicine is the standard practice. To support state-of-the-art research and medical care, the facilities must also be state-of-the-art; therefore it is the intent to build and maintain the physical plant and facilities in accordance with the latest standards.

It has been the NIH experience that renovation/rehabilitation of existing facilities do not lend themselves to incorporating the “latest” standards of the industry, primarily due to outdated and inadequate mechanical systems or because the planned function is incompatible with the original criteria for the facility.

The Architect and Engineer (A/E) shall be alerted to this type of situation and make an evaluation early in the design stage to determine the feasibility of the implementing latest standard. The A/E shall document such findings, provide recommendations, and report them to the Project Officer for a decision on how to proceed.

The A/E design firm shall use and comply with, as a minimum, the latest issue of the following design and safety guidelines. In addition, the A/E shall use other safety guidelines received from the NIH Project Officer or as required by program. The A/E shall utilize the latest versions of guidelines available at the time the project proceeds with schematic design.

The design and safety guidelines include but are not limited to the following:

- The BOCA International Building Code
  The International Mechanical Code
  The International Energy Conservation Code

  Building Officials and Code Administrators (BOCA) International, Inc.: 4051 W. Flossmoor Road, Country Club Hills, IL 60477-5795. Telephone 708-799-2300 ext. 242.

- ASHRAE Handbooks and Standards
  American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Inc.: 1791 Tullie Circle, N.E., Atlanta, GA 30329. Telephone 404-636-8400.

- *Industrial Ventilation: A Manual of Recommended Practice*
  American Conference of Governmental Industrial Hygienists, 6500 Glenway Avenue, Bldg. D-7, Cincinnati, OH 45211.

- *American National Standard for Emergency Eyewash and Shower Equipment (ANSI Standards Z358.1)*
  Industrial Safety Equipment Association NY, American National Standards Institute (ANSI). Telephone 212-642-4900.

- *Planning and Design of Laboratory Facilities*
  Baker, J. H., Houang, L. (1983) the World Health Organization (WHO), Offset Publications, 72: 45-71.6.

- *Occupational Safety and Health Standards*, CFR 29, Part 1910
  U.S. Department of Labor, Occupational Safety and Health Administration, (OSHA). Telephone 202-783-3238.

- *Guidelines for Research Involving Recombinant DNA Molecules*
  U.S. Department of Health and Human Services, U.S. Public Health Services, National Institutes of Health, Federal Register/Vol. 51, No. 88: 16957-16985, Bethesda, MD: National Institutes of Health. Telephone 301-496-9838.

- Standard 49 for Class II (Laminar Flow) Biohazard Cabinetry
  National Sanitation Foundation Joint Committee on Biohazard Cabinetry. Ann Arbor, MI: National Sanitation Foundation. Telephone 313-769-8010.

- VFD Study, Dr. F. Memarzadeh

- *NIH Guidelines on Optimization of Laboratory Hood Containment 1996: Dr. F. Memarzadeh,/ Flomerics.*

- *NIH Guideline on Enhancing the Design of Animal Research Facilities 1997: Dr. F. Memarzadeh/ Flomerics.*

- *Laboratory Safety Monograph: A Supplement to the NIH Guidelines for Recombinant DNA Research*, U.S. Department of Health and Human Services, U.S. Public Health Service, National Institutes of Health Bethesda, MD: National Institutes of Health. Telephone 301-496-2960.

- *Guidelines for Laboratory Design: Health and Safety Considerations*
  DiBernardinis, L., and J.S. Baum, M.W. First, G.T. Gatewood, E.F. Gordon, and A.K. Seth. 1987. New York: John Wiley and Sons.

- *Biosafety in Microbiological and Biomedical Laboratories*
  U.S. Department of Health and Human Services. Washington, DC: Public Health Service, Centers for Disease Control, and National Institutes of Health, HHS Pub. No. (NIH) 88-8395.Telephone 202-783-3238.

- *NIH Guidelines for the Laboratory Use of Chemical Carcinogens*
  U.S. Department of Health and Human Services, Bethesda, MD: National Institutes of Health, NIH Pub. No. 81-2385. Telephone 301-496-2960.

- *National Fire Codes, all volumes*
  National Fire Protection Association, (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101, Telephone 617-770-3000.

- *Guide for the Care and Use of Laboratory Animals*
  U.S. Department of Health and Human Services, Bethesda, MD: National Institutes of Health, Pub. No. 86-23, Telephone 202-783-3238.

- *Guidelines for Construction and Equipment of Hospital and Medical Facilities*
  The American Institutes of Architects Committee on Architecture for Health with the assistance from the U.S. Department of Health and Human Services. American Institutes of Architects Press, 1735 New York Avenue, NW, Washington, DC 20006. Telephone 800-365-2724.

- *Medical Laboratory Planning and Design*
  College of American Pathologists, Skokie, IL. Telephone 708-446-8800 Ext. 531.

- American Society of Hospital Engineering, all volumes
  American Hospital Association, 840 North Lake Shore Drive, Chicago, IL 60611.

- *Regulations Governing the Installation of Plumbing, Gas Fitting and Sewer Cleaning in the Washington Suburban Sanitary District*
  Washington Suburban Sanitary Commission, (WSSC), 4017 Hamilton Street, Hyattsville, MD 20781.

- *Standards for Medical-Surgical Vacuum Systems in Hospitals*
  PAMPHLET p-21, Compressed Gas Association (CGA).

- Uniform Federal Accessibility Standards, FED STD 795

- ANSI Standard Z 358.1
  American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

- *ASPE Data Books*, all volumes and supplements
  American Society of Plumbing Engineers, (ASPE), 3617 Thousand Oaks Blvd. #210,Westlake, CA. 91362.

- *National Institute of Health Direct Digital control specifications Guidelines, 1995, Dr. F. Memarzadeh*

D.2 Building Design Considerations

The Project Engineer shall include at the completion of the schematic design phase a Basis of Design report. The report shall be a bound presentation with documentation sufficiently complete to justify the complete design concept of the A/E. Detailed building design criteria, computations, schematic system diagrams, economic analysis, and life cycle costing comparisons shall be included as a part of the Basis of Design report.

The Project Engineer shall include, as a minimum, evaluation of the following topics prior to completion of the schematic design phase. Results of the evaluation shall be defined in the Basis of Design report.

General Mechanical:

- Project utilities and capacities
- Outdoor design conditions
- Indoor design conditions
- Ventilation/indoor air quality requirements
- Mechanical equipment locations and access
- Distribution of mechanical services
- Zoning, modularity, and flexibility
- Energy conservation plan and opportunities
- Control methodology
- Moisture control methods
- Redundancy and reliability

Supply/Return Air Systems:

- Location of air intakes in relation to all exhaust discharges
- Supply/return air system components
- Supply/return air distribution
- Air velocities through equipment and ductwork distribution
- Location of supply/return air in room
- Air supply/return flow control and quantities
- Relative room pressurization and airflow direction
- Filtration requirements
- Humidification criteria
- Noise criteria
- Redundancy and reliability

- Control zoning
- Measuring and monitoring methodologyExhaust Air Systems:

Exhaust air system components

- Chemical fume hoods
- Biological safety cabinets
- Dedicated perchloric acid fume hoods
- Dedicated radioisotope hoods
- Compatibility of individual exhaust, i.e., chemical with general exhaust
- Local exhaust systems/general building exhaust
- Compatibility of exhaust distribution system with exhausted chemicals
- Exhaust air flow control and quantities
- Filtration requirements
- Redundancy and reliability
- Exhaust stack design and height
- Noise criteria
- Air velocity through equipment and ductwork distribution
- Capture face velocity through fume, canopy, and point exhaust hoods
- Generator exhaust
- Processing equipment exhaust
- Measuring and monitoring methodology

D.3 Energy Conservation

The BOCA Interational Energy Conservation Code shall be utilized to regulate the design and construction of the exterior envelopes and selection of HVAC, service water heating, electrical distribution and illuminating systems, and equipment required for the purpose of effective use of energy, and shall govern all buildings and structures erected for human occupancy. When requirements of the energy conservation code cannot be satisfied because of program requirements, the NIH Project Officer shall be notified.

At the completion of the design development phase, a plan review record as defined in the BOCA International Energy Conservation Code shall be submitted stamped and signed by a licensed professional engineer showing full compliance with the code.

Minimum system insulation thicknesses shall be as required by the energy conservation code and ASHRAE recommendations. The minimum thickness in all applications shall be sufficient to prevent the possibly of condensation.

The quality of the building environment shall be supportive of the health and safety of staff and patients. Opportunities for conserving energy resources shall not compromise staff or patient health and safety nor hinder continuous research functions.

Effective energy management requires close, consistent control of all energy consuming systems and components. A buildingwide energy management and control system shall be provided to monitor and control energy consuming systems.

Systems using a high percentage of outdoor air or 100% outdoor air should consider the use of heat reclamation equipment. The capital cost, energy cost, maintenance cost, and payback period of the of heat reclamation systems shall be evaluated for the use at the NIH. Evaluations shall be compared to systems employing no heat recovery or energy conservation components.

D.4 Heat Reclamation

Heat reclamation is the recovery and utilization of heat energy that is otherwise rejected as waste. Sources of this waste heat include exhaust air, lights, equipment, and people. Heat reclamation systems recover waste heat to satisfy part of the heat energy needs for heating, cooling, and domestic hot water systems. Heat recovery conserves energy, reduces operating costs, and reduces peak loads.

The performance of any heat recovery system depends upon the following factors: temperature difference between the heat source and heat sink; latent heat difference (where applicable) between the heat source and sink; mass flow multiplied by specific heat of each source and sink; efficiency of the heat-transfer device; extra energy input required to operate the heat recovery device; fan or pump energy absorbed as heat by the heat transfer device; and service capability of the maintenance staff, which can enhance or detract from the performance.

The basic principles of heat recovery can be implemented by various methods using different devices applicable to different systems or situations. Heat recovery devices reduce the peak heating and cooling loads when used with outdoor air systems.

The A/E shall determine the life cycle cost for the following heat reclamation systems to determine their applicability. Consideration shall be given to the functional space requirements of the system and components.

D.4.1 Runaround System

This system is comprised of two or more extended surface coils installed in air ducts and interconnected by a piping system. The heat exchanger fluid, consisting of ethylene glycol and water, is circulated through the system by a pump, removing heat from the hot air stream and transferring it to the cold air stream. A runaround-coil system may be used in winter to recover heat from warm exhaust air for use in preheating cold outdoor air, and in summer to cool hot outdoor air by transferring heat to cooler exhaust air.

D.4.2 Heat Pipe Systems

Heat pipe systems are composed of extended surface finned tubes extending between adjacent air ducts. The tubes are continuous from one duct to the other on the same horizontal plane. Each tube contains liquid refrigerant which evaporates at the warm end, absorbing heat from the warmer airstream, and migrates as a gas to the cold end where it condenses and releases heat into the cold airstream. The condensed liquid then runs back to the hot end of the tube to complete the cycle.

D.4.3 Plate Heat Exchanger

Plate-type air-to-air heat exchangers transfer heat from one airstream to another through contact on either side of a metal heat-transfer surface. The systems shall have no cross flow and provide antiseptic odor-free air as well as adaptability to extreme sensible and latent heat loads. Plate heat exchangers require the installation of supply and exhaust ducts side by side.

D.4.4 Heat Wheels

Desiccant coated molecular-sieve heat wheels transfer only water vapor and exclude all other airborne materials, thereby eliminating the risk of cross contamination. The systems shall have less than 1% cross contamination and provide antiseptic odor-free air as well as total energy recovery.

D.4.5 Heat Pump as Heat Exchanger

Heat pumps are actually heat-transfer devices and, unlike those previously described, upgrade the temperature by as much as a factor of 3 to 1. This feature makes them particularly attractive for use with low-temperature heat sources. They also have the capacity to transfer latent heat as well as sensible heat.

D.4.6 Thermal Storage Systems

Systems employing the use of the various thermal storage technologies and applications shall be considered when the design criteria afford the opportunity. Systems to be considered include ice, chilled-water storage, and the various types of low-temperature air distribution. Thermal storage comparisons shall consider that central chilled water is available year round from the power plant.

D.4.7 Motors and Drives

Motors form a large portion of building energy load and are usually part of the mechanical systems of the building. High-efficiency motors generally have a payback of 2 years or less. Variable-speed drives usually have similar results depending on the variability of the driven load and therefore shall be considered for application in buildings. Power factor correction capacitors shall be employed on applicable motors to satisfy code requirements.

Two-speed motors shall be used where a fan or pump has two levels of operation, such as occupied/unoccupied. Two-speed motors come in two varieties: single winding and two winding. For most pump and fan applications, a variable torque, one-half speed motor is used.

Several types of variable-speed drives are available: mechanical, fluid, and variable frequency/voltage units. The variable frequency/voltage drives vary the output for a standard alternating current (AC) motor by varying the input frequency and/or voltage to the motor. Where required, special filtering should be included. These types of drives provide the highest energy savings and shall be used for fans or pumps with throttling devices that vary output according to needs.

D.4.8 Gravity Flow Systems

Gravity flow open-water systems shall be considered to reduce the run time of system pumps. These systems have a limited application and may apply to plumbing systems only.

D.5 Systems Economic Analysis

The purpose of the economic analysis is to determine the comparative life cycle costs of various HVAC system alternatives. The analysis shall provide sufficient data to indicate the most economical and energy-efficient system and to permit a comprehensive review of all computations. The analysis shall include and compare total initial capital cost, energy cost, operating cost, system reliability, flexibility, and adaptability for each alternative. Each system alternative considered shall satisfy completely the program requirements as to flexibility, redundancy, reliability, and ease of maintenance. The total capital cost to provide the program requirements for each alternative shall be included as part of the life cycle cost.

For comparison of systems, the life cycle and operating cost shall be 30 years corresponding to anticipated useful life for major equipment. Replacement costs shall be included for equipment with less than the chosen life cycle.

- The escalation rate for fuel or energy cost, i.e., oil, gas, coal, electricity, etc., shall be according to procedures set by the Department of Energy (DOE) in NIST Handbook 135, *Life Cycle Cost Federal Energy Management Program*.

- Initial capital cost shall include all equipment, auxiliaries, and building-related cost for each complete system. Refer to ASHRAE for *HVAC Systems and Equipment Handbook*, chapter on “Owning and Operating Costs,” for a complete listing of items to be included in the economic analysis.

- The A/E shall perform a computerized energy analysis and a life cycle cost analysis using a professionally recognized and proven program which makes hourly calculations as a basis. Suitable programs include Carrier EC 20-11 HAP, DOE 2.1, and Trane Trace-Ultra. If other programs are to be considered, documentation showing Federal and State approval should be forwarded for approval prior to the start of work. Manual or computerized spreadsheet methods may be used to evaluate system alternatives when approved by the NIH Project Officer.

- Building HVAC systems suitable for consideration in economic analysis include the following systems or combinations of systems:

- Variable air volume (VAV) with reheat terminal units
    - VAV with independent perimeter heating
    - Constant air volume (CAV)
    - CAV with reheat terminal units
    - CAV with independent perimeter heating
    - Fan-powered VAV with terminal reheat units
    - Dual-duct VAV
    - Dual-duct CAV
    - Fan-coil air conditioners
    - Induction air system.
    - Low-temperature air system.

D.6 Energy Cost

Energy cost computations shall take the base load into consideration. Utility usage and rates shall be provided by the NIH. Backup computations for items listed in the operating cost shall be included.

Computation shall be made on a monthly basis taking into account variations in the heating and cooling loads. Energy usage and cost shall be developed by computer programs using weather bureau tapes or by using Air Force Manual AFM-88-8, *Engineering Weather Data* and the bin method procedure referenced in the latest *Fundamentals* volume of the ASHRAE *Handbook.*

Energy cost computations shall take into consideration the energy used by fans, and cooling and heating coils in the system as well as refrigeration plant energy costs that are brought about as a result of the type of air-conditioning system in the building.

Steam cost shall be as provided by the NIH.

D.7 Life Cycle Cost Calculations

For cost comparison, amortization of first cost and the present worth of life cycle operating costs shall be calculated and combined, as follows, to obtain the present worth and annual owning and operating costs of each system.

Public Law 95-619 requires that life cycle cost analyses for federal projects conform to procedures set forth by the DOE. The following factors are used for the life cycle cost analysis:

- Interest (discount) rate of 7% for future costs
- Zero inflation factor for all future costs other than fuel
- Fuel inflation factors as determined by the DOE in the latest supplement to NIST Handbook 135 that represents the extra inflation of fuel over general costs. The fuel inflation factors can be expressed and used as modified uniform present worth (UPW) discount factors which, when multiplied by the first-year fuel costs, give the present worth of a series of escalating annual fuel costs. These factors are published for four Census regions.

Total “present” worth is equal to the sum of the first (construction) cost and the present worth of maintenance, replacements, utilities, electricity, and fuel payments for 30 years. All of the above “present” worth should be based upon appropriate construction schedules.

The annual equivalent cost is the payment that will amortize the total present worth in years at the given interest rate using a capital recovery factor (CRF) cost. Taxes or insurance are not included in the annual owning cost.

D.8 Noise and Vibration

D.8.1 Introduction

These design guidelines are intended to provide general information about noise and vibration control to project engineers charged with designing mechanical and electrical systems for the NIH. They cover situations that arise in the design process and significant items to check at design reviews. As a supplement to other sources of technical information such as the Sound and Vibration Control section of the ASHRAE *Systems and Applications Handbook* and the advice of an acoustical consultant, they are intended to help the engineers to achieve appropriate sound and vibration levels required by the program functions.

D.8.2 Background Noise

All rooms in all buildings, except special acoustical laboratories, are exposed to some level of audible and measurable ambient sound. It may be due to nearby street traffic, but more often it is governed by the building's own mechanical system. Ambient sound should be, and usually is, anonymous in character. This is an accepted acoustical condition to which we are almost always exposed. The ambient sound should never be so loud as to interfere with speech or telephone use in a space. Yet frequently the presence of modest levels of ambient sound is needed to mask distracting extraneous sounds.

Each such noise is characterized by a certain spectrum indicating the sound pressure level at various frequencies. Very often, the spectrum of a noise is as important as its absolute level. Although speech and airplane takeoff may be perceived as being about the same loudness, it is much more difficult to attenuate the lower-frequency noise. The level of such background sounds is commonly related to a series of noise criteria (NC) or room criteria (RC) curves. These spectra have been developed to account for the approximate sensitivity of the human ear to high-frequency noise over low-frequency noise and also to the typical spectrum of human speech. The NC/RC value for a given spectrum is then determined by its highest point in relation to the NC curves. To determine the NC/RC value in the field, sound pressure levels should be measured with an octave-band sound-level meter.

For most spaces, recommended NC/RC levels have been established through many years of experience. In general, for areas where listening is critical and speech communication is important, the NC/RC level should be low. For areas where speech is at close distances (1.8-3.0 m), the NC/RC level may be higher. Table No. 1 lists recommended NC levels for a variety of spaces. NC levels are based on rooms not being occupied and with all user equipment off.

Table No. 1
Recommended NC Levels

Area	NC Level
Auditoriums	20-25
Audiology Suites, Audio/Speech, Pathology, Phonology/Cardiac	25
Chapel, Chapel Meditation	25
Private Residences	25-30
Conference Rooms	25-30
Hospital Rooms	25-35
Patient Rooms	35
Executive Offices	30-35
Classrooms	30-35
Open-Plan Offices	35-45
Dining Rooms, Offices, Lobbies	40
Central Sterile, Food Service/Serving	45
Operating Rooms	40-45
Research Laboratories	40-45
Corridors	45
Kitchen, Lockers, Warehouse, Shops	50
Research Animal Housing Areas	*

The above NC values may be increased for unitary or user equipment installed within occupied spaces as approved by the Project Officer.

The sound levels apply to these spaces in most common situations. If the users of the space are hearing impaired, then the tolerance for high background noise levels is greatly reduced. For situations involving audiological testing, there are very specific requirements. In either of the latter two cases an acoustical consultant should be involved in the design at an early stage.

Systems must be engineered and the use of sound attenuation provided as required to achieve specified sound levels.

* When evaluating the noise levels which should be provided in research animal housing areas, it is necessary to consider both the people and the animals in these spaces. For reasonable speech communication in these spaces, a maximum noise level of NC-45 should be maintained. Specific requirements for vivarium areas shall be determined by the acoustical consultant with the project officer and research staff.

Both the Project Engineer and the building owner should be aware of the costs and benefits related to the choice of noise criteria or room criteria curves. Studies have shown RC curves to have a more desirable spectrum for background noise. However, RC curves may require more noise reduction in lower-octave bands than would be required for an NC curve. This noise reduction may entail significant costs in equipment and operations. For spaces at about NC-30 or NC-40, the duct silencers will be 1-1/2 to 2 times longer and pressure drop will increase 10% to 20%. If architectural constructions are used for noise control, they will also be more massive and elaborate. In general, NC curves provide a more reasonable fit between costs and benefits and shall be utilized for NIH buildings.

D.8.3 Scientific Equipment Noise

The design team should be aware that there are many noise sources in health care and research facilities which are not related to the building mechanical system. NIH buildings are often equipped with refrigerators, centrifuges, and other scientific equipment that contribute significantly to the ambient noise level. In some cases, this equipment will be located in service corridors and adjacent to occupied spaces.

Scientific equipment includes a great variety of sources. Most of this equipment operates intermittently and is often under the control of the user. Since the types of equipment vary greatly, it is not possible to prescribe a single means of noise control. We recommend that equipment which produces significant amounts of noise be considered during the design stage. Any equipment that either produces noise levels in excess of 50 dB(A)) at a distance of

914 mm, or is simply known by the laboratory users to produce objectionable noises, should be considered a significant noise source.

For adequate speech intelligibility at a distance of 1.8 m, with normal voice effort, the background noise level should not exceed 50 dB(A) or NC-45. In addition, the background noise spectrum should not interfere with speech intelligibility. Since the bulk of speech intelligibility is in the 500 to 4000 Hz octave bands, sound levels should be lower in that area. A goal of NC-45 is equal to 53 dB(A) and has been designed to account for the frequency distribution of speech intelligibility. NC-45 should be used as a maximum design goal for occupied research areas in NIH buildings.

As noted previously, refrigerators and other scientific equipment are frequently removed from occupied areas and placed in corridors. In many cases, this alone can cause fairly high noise levels. Because of this, noise levels of NC-45 in corridors and support areas are recommended.

D.8.4 Background Noise for Open Offices

Most office workers have difficulty concentrating when distracted by conversations and intruding noises. In open-plan offices, voices and the sounds of other activities are easily transmitted between work stations because there are no full-height partitions or barriers. Even with the most effective acoustical treatment on the partial-height partitions and ceilings, the intruding sounds will be clearly audible unless they are masked by other sounds. For this reason, providing such masking sound is essential in the design of any open-plan office where speech privacy or the ability to concentrate is important.

Even in buildings with conventional enclosed offices, full-height partitions may not provide adequate acoustical isolation for confidential speech privacy if the background sound levels are too low. Installation of a sound-masking system can be the least expensive, simplest way to achieve satisfactory privacy.

For satisfactory performance, a sound-masking system must provide an even blanket of sound throughout the office. The masking sound must be free of annoying spatial or temporal differences in loudness and must provide specific levels of sound at specific frequencies. At the same time, it must be unobtrusive in overall level and character so that it is not, in itself, an annoyance to the office occupants.

Elevated background noise levels can, however, cause problems for hearing-impaired employees. If it is known that one or more hearing-impaired employees will be working in an area, then the designer should endeavor to provide a space with low background noise levels and a significant amount of acoustical absorption. If a sound-masking system is provided, the use of adjustable levels in zones can be beneficial.

D.8.5 Design Guidelines

The evaluation of mechanical system noise should take place in the early design phase of a project. This evaluation is as important as thermal load calculations. System noise calculations are the responsibility of the Project Engineers designing the system, unless an acoustical consultant is employed.

It is not recommended for a Project Engineer without experience in acoustical matters to attempt to “wing it” through an acoustical analysis of a major project. It is the experience of the NIH that about two-thirds of these analyses are wrong in very elementary ways, and the monetary consequences to correct acoustical deficiencies can be quite substantial.

D.8.6 Noise Control

<u>Mechanical Equipment Rooms</u>: For most large buildings, there will be two types of mechanical rooms. One will be central mechanical rooms, and the other will be individual floor mechanical rooms. To begin an analysis of the requirements for sound attenuation and vibration isolation of the mechanical room, two items must be identified. The first is requirements of adjacent rooms, both in plan and in section. The second is the type and size of equipment in the mechanical room. The selections need only to be general at this point. Reasonable sound-level estimates can be made without specific manufacturer's model numbers for standard equipment.

The ASHRAE *Systems and Applications Handbook*, for Sound and

Vibration Control allows the Project Engineer to make general estimates of equipment noise levels. For significant equipment, manufacturers should be asked to provide laboratory-generated sound power levels. These should then be incorporated into the equipment requirements of the project specifications. In many cases, it may be possible to minimize expensive noise control measures if quieter equipment can be selected.

At this point, it is possible to estimate the noise reduction requirements for the mechanical room. If a mechanical room is to be located below or above a noise-sensitive space, this should be identified early in the design. If the floor slab above or below mechanical equipment is not sufficiently massive to provide adequate noise isolation, then it may be difficult to modify it after the structural system has been sized and set. At this point, there are two solutions that are often used. One is a floating floor, and the other is a resiliently suspended gypsum board ceiling in the mechanical room or in the noise-sensitive space below. The first is very expensive, and the second is very difficult to install properly in the equipment room below because of pipes, conduit, and equipment. Spaces underneath mechanical rooms face similar problems, but it is generally easier to install a suspended gypsum ceiling in a conference room or office than in a mechanical room.

If possible, the mechanical room should be located away from noise-sensitive spaces. Buffer spaces such as corridors, toilets, elevator shafts, electric closets, and other service spaces may eliminate the need to build special noise-isolating constructions such as floated floors or double-layer wall constructions. In all cases, central mechanical rooms in occupied buildings should have heavy walls of masonry or poured concrete. All penetrations of walls, floors, and ceilings by ducts, pipes, conduit, etc. should be resiliently sealed airtight. Particular attention should be paid to doors, as these often represent the “weak link” in sound isolation. Gasket systems to seal air leaks are available when required.

Mechanical equipment spaces located within the NIH buildings shall have a sound-absorbing treatment installed on the walls and ceiling. At least 30% percent of the available wall surfaces and 50% of the ceiling surface shall be covered with a sound-absorbing treatment. The preferred material is a glass fiberboard having a density in the range of 24 to 64 kg/cm. Other sound-absorbing materials can be used, except cellular plastic materials, and these shall provide a minimum noise reduction coefficient (NRC) of 0.65 for a 25 mm thickness and a minimum NRC of 0.80 for 50 mm and 75 mm thicknesses as determined by American Society for Testing and Materials (ASTM) C 423. They shall also provide a minimum flame-spread rating of 25 and a minimum smoke-developed rating of 50 as determined by ASTM E 84.

The minimum thickness of the sound-absorbing glass fiber material used in equipment spaces shall be as follows:

Space Contents	Minimum Thickness of Sound-Absorbing Treatment (millimeters)
Boilers and Emergency Generators	75
Chillers and Fans	50
Pumps, Compressors, Transformers, Elevator MG Sets, and Switchgear	25

Consideration should be given to the application of enclosures or jackets over generators to provide additional attenuation for equipment operators within the space.

Sound-absorbing treatment also reduces the noise levels in mechanical equipment and other high noise-level spaces and helps reduce the possibility of hearing damage to maintenance personnel. Tabulated below are the maximum allowable noise exposure limitations for hearing conversation of individuals in high noise-level areas, as defined by the Occupational Safety and Health Act (OSHA) of 1970.

Exposure Duration Hours per Day	Sound Level, OSHA Limits (d B (A))
8	90
6	92
4	95

3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 and less	115

Airborne Noise Control: In designing a building HVAC system, it is most common to size ductwork on an equal-friction basis and consider velocities indirectly, as they relate to the volume flow and pressure drop in the ducts. For purposes of noise control, it is often necessary to consider duct velocity for its own ability to generate noise in a system. (A noise source; velocities in airflow generate turbulence and therefore noise.) The amount of noise generated is proportional to 50 x log (velocity). Because of the uncertainties involved in calculating exact velocities through elbows, dampers, and other fittings during the design process, it is often best to use general guidelines. The path of noise to any potential receiver should be examined. In most cases, the dominant path for noise is through the duct to a room outlet. In more severe cases, noise from turbulence may "break out" of the duct and enter a space directly. The final general area to consider is the acceptable noise level at the receiver location. Duct velocities serving auditoriums must be considerably less than those serving research laboratories.

The selection of quieter, initially more expensive equipment is generally more economical than a less expensive type which requires considerably more noise and vibration control. Measured sound-power ratings should be supplied by the manufacturer and shall be a factor in the selection of each major piece of mechanical equipment.

Low- or medium-air velocity systems shall be used. Low- velocity distribution requires less energy to move the air and also greatly reduces the generation and regeneration of noise produced by high velocities.

Table No. 2 lists recommended velocities for ductwork serving spaces with a given NC rating. When measuring distance from the air terminal, it is important to measure from each terminal, not just the last one. In this case, the "terminal" is a bit different from what is used for static pressure calculations. These velocities may be increased if all paths to the receiver from the turbulence in the duct are considered. In general, this means installing a silencer along the duct. To prevent breakout noise, a duct enclosure or architectural construction must also be used.

Table No. 2
Recommended Maximum Air Velocity in Duct System
(Air Velocity in m/s to Yield NC Indicated)

Location	NC-25		NC-30		NC-35		NC-40		NC-45	
	Supply	Return	Supply	Return	Supply	Return	Supply	Return	Supply	Return
Air velocity through net free area of terminal device 13 mm minimum slot width	1.78	2.13	2.16	2.59	2.54	3.05	3.05	3.66	3.66	4.37
3 m of duct before opening	2.13	2.49	2.59	3.05	3.05	3.56	3.66	4.27	4.37	5.08
Next 3 m	2.84	3.20	3.45	3.89	4.06	4.59	4.88	5.49	5.84	6.60
Next 3 m	3.56	4.06	4.32	4.93	5.08	5.28	6.10	6.35	7.32	7.62
Next 3 m	4.57	4.98	5.49	6.00	6.50	7.11	7.78	8.53	9.35	10.23
Next 3 m	5.19	6.40	6.91	7.82	8.13	9.14	9.75	10.97	11.68	13.21
Next 3 m	7.11	7.82	86.36	9.50	10.16	11.18	12.19	13.41	15.24	16.10

Note: Velocities for exhaust systems should refer to recommended return velocities.

Rooftop Equipment: For some buildings, packaged rooftop or commercial-grade unitary equipment may be used rather than having equipment located in central or individual mechanical rooms. Special care should be taken in the location, selection, and design of this type of equipment. The roof structure should be sufficiently stiff that it does not vibrate with the equipment. Most commonly used vibration isolation selection tables assume a reasonably stiff supporting structure. In the case of many lightweight roofs, that assumption is neither safe nor accurate. From an acoustical viewpoint, the preferred mounting arrangement is to place the unit above the roof by 610 mm or 915 mm on supplemental steel framing. Equipment manufacturers' internal vibration isolation furnished as standard or optional equipment may not be adequate for controlling the transmission of noise and vibration. The required deflection should be maintained for either internal or external isolation. However, manufactured, spring-isolated roof curbs are available with integral isolation. These units can provide spring deflections ranging from 6 to 75 mm and can be used as an acceptable option. Curb isolation may be adequate, but proper isolator selection is important to compensate for each building construction condition. In addition to structural vibrations, the noise radiated from the unit casing and the supply and return ductwork must be considered. In most of these cases, there is a potential noise problem that would almost always be worst directly under the unit. In addition to these unique problems, normal ductborne fan noise should also be considered. All of this is not a reason to eliminate the use of rooftop equipment, but it is necessary to review these points to properly evaluate all these potential problems. It is recommended that housed-type vibration isolation mounts not be allowed.

Noise Outside Equipment Rooms: Many noise problems with mechanical systems are associated with that part of the building just outside the equipment room. This type of noise is generated in two ways. The most common is noise generated by the fan that is propagated within the ducts to outlets. The second type is noise generated by air turbulence at fittings, vanes, and dampers. High-pressure, high-velocity systems will often have significant quantities of both types of noise and vibration.

The noise generated by ducted systems will typically enter spaces in three ways. It may pass through the duct walls and into noise-sensitive spaces. It may travel within the ductwork and enter a space through supply or return grilles. Finally, vibrations in the duct may be transmitted into other surfaces or utility systems to either create noise or become feelable vibrations. This final type will be covered in section D 8.8, Vibration Isolation.

Noise which passes through duct walls is usually referred to as “breakout” or “break-in” noise. This noise may be either fan noise or velocity-generated fitting noise. Only in the case of a lightweight fiberglass ductboard does the sound literally pass through the duct wall unattenuated. This is often a problem closest to the fan. At this point, the ducts are large and therefore not very stiff. Near the mechanical room, noise from the fan has not been attenuated by long runs of ducts. This usually causes a low- frequency rumble in the vicinity of main ducts, especially if the duct is directly above a lay-in acoustical tile ceiling.

Exposed duct, in itself, does not create a noise problem. In the case of exposed ducts, breakout noise would not be attenuated by a ceiling. However, the noise reduction provided by a lay-in ceiling is negligible at low frequencies. Calculations based on ASHRAE *Systems and Applications Handbook's* Sound and Vibration Control section should be performed to determine the likelihood of a problem. Should there be a problem, there are several methods to reduce the potential noise level. First, the duct may be rerouted over a noncritical area. Second, round duct or multiple round ducts may be used in lieu of rectangular duct if adequate space is available, since round duct is stiffer. Third, the duct may be externally wrapped or encased. The final two methods are difficult to do well.

Duct wrappings may encounter sufficient numbers of obstructions and penetrations to render them ineffective. Access to valves and duct mounted equipment becomes difficult. While wrapping can be effective, it should be employed only when absolutely necessary.

Ductborne Noise: The passage of noise from the fan along inside the duct and into a space is one of the most common noise problems associated with mechanical systems. The engineering procedures to deal with this problem are also well documented in the ASHRAE *System and Application Handbook's* Sound and Vibration Control section. It should be pointed out that this method can also be used to calculate the propagation of noise generated at fittings and dampers away from the fan. This is particularly relevant in the design of laboratory exhaust systems where the velocities and pressures in the systems are often quite high. In these circumstances, high levels of noise may be generated at fittings and volume-regulating dampers. For laboratory systems in particular, this noise should be included in the acoustical analysis of the system.

Within the duct system there are several items which provide some attenuation of noise. These are branch takeoffs, open-end reflections, fittings, and duct silencers. These are all discussed in detail in the ASHRAE *Handbooks*, so only some minor points will be discussed here. Branch takeoffs provide a division of sound energy proportional to the decibel ratio of the areas involved. For example, assume the room in question is served by a 508 x 254 (129,040 mm^2) branch from a 1219 x 1219 (1,486,541 mm^2) trunk. The attenuation provided is 10 x log (200/200 + 2,304) or 11 dB. This credit should only be taken where one of the branches does not enter the room in question. Where a fan serves many rooms, this can be a substantial help. Duct lining is one of the most efficient noise control measures available, but lining is not approved for use in NIH buildings.

Manufactured duct silencers are another commonly used means of noise control. These are commercially manufactured sound absorbers. They consist of a section of sheet metal with perforated interior skin and sound absorbing in-fill. They are available in many constructions, sizes, and shapes. In general, these factors can be matched to the requirements of the system under design. In the design of hospital, animal, and laboratory systems, it may not be appropriate to allow standard perforated, fiberglass-packed, galvanized silencers. Alternately, a requirement for high-grade stainless steel, packless washable silencers may be necessary. Silencer manufacturers can also provide thin plastic bags for the fill. They also provide a thin mesh screen between the bagged fill and the perforated metal baffles to assure minimum degradation of acoustical performance. Insertion loss and spectrum level are also important characteristics when selecting duct silencers. Generally, the 125, 250, and 500 Hz octave-band center frequencies are most critical. Ductborne sound-level calculations will provide the required insertion loss for a silencer. Sample calculations provided by some manufacturers will often show a very close match between the octave-band insertion loss requirements and the performance of the silencer that is chosen. This does not usually happen in real-world situations. The insertion loss requirement for the silencer will usually be dominated by one or two low-frequency octave-band center frequencies depending on fan type, blade passage frequency, and blade configuration, which affect the fan sound-power level. The other factors in silencer performance which should be considered are size and pressure drop. It is usually possible to meet the insertion loss requirements with several different-sized silencers. That choice is usually between a long, low-pressure drop silencer and a shorter, high-pressure drop silencer. At this point, the engineer must make a choice between system operating cost and first cost. Once a silencer is selected, it must be incorporated into the duct layout. The silencer should be located so that smooth airflow is maintained into and out of the silencer. Poor design in these areas can cause the actual pressure drop to be much more than that listed by the manufacturer and can also degrade acoustical performance. Proper specifications should require ratings in dynamic insertion loss (DIL), i.e., with air flowing through the silencer. All supply and return exhaust air (research laboratory and vivarium only) systems shall use packless type silencers. Silencers such as IAC type HS may be used for all supply boxes if they are clean flow boxes with tedlar or other coverings confirming to NFPA 90 standard over perforated metal cover liner with an erosion proof surface meeting ASTM C 1071- 91 test. The liner must have passed and shown NO observed growth for the test for mold growth and humidity using UL 181 test, fungi resistance ASTMC 1071 and ASTMG-21 tests and bacteria growth using ASTMG 22 test.

It is important in locating the silencer to keep in mind that any noise generated downstream or upstream in the case of exhaust systems from the silencer will not be attenuated. For a laboratory system, it is important to remember that constant-volume-regulating dampers will usually generate a substantial amount of noise, especially if there is a substantial pressure drop (more than about 25 mm) across the regulating damper. If the silencers are placed near the fan, then noise generated by these dampers will enter the laboratory unattenuated by the silencers. For spaces with critical listening requirements, such as auditoriums and large conference rooms, similar problems can be created by excessive velocities at supply or return terminal devices. Since the amount of noise is velocity related, it is advisable to elect terminal devices with more free area for critical spaces.

<u>Miscellaneous Mechanical Equipment</u>: In some cases, the engineer may be concerned with noise from relatively small pieces of equipment, particularly if they are located in an occupied space, rather than in a remote mechanical room. These include “active” devices and “passive” devices. Active devices are most often items such as fan coil units, heat pumps, or air terminal units. Passive devices are most often diffusers, air-monitoring devices, grilles, and louvers.

For the active devices most manufacturers can provide octave-band sound-power levels. For passive devices manufacturers' ratings may also be provided. In general, these can be used if some attention is paid to quantity of diffusers in a room.

Hoods with velocities around 0.76 m/s will almost never be a direct cause of noise. System noise may come out of the hood, though. The same is true of louvers. Noise may often be heard coming out of these devices, but they are not often the actual cause of the noise.

Steam pressure-reducing stations and other major pressure control devices can generate significant noise within mechanical rooms. Design documents shall require valve manufacturers to meet a specified noise criterion with the possible use of noise suppressors.

D.8.8 Vibration Isolation

Structure-borne sound is produced by a noise source, such as a piece of vibrating machinery, which transmits energy directly into and through the structure, often to remote locations in a building, and is reradiated by wall and floor construction as airborne noise. All vibrating equipment in facilities shall be resiliently mounted.

The purpose of vibration isolation is to reduce the vibrational energy produced by rotating equipment so that it is not passed into the structure and into larger "sounding boards" where it can be translated into audible noise. In the cases of some sensitive scientific equipment, structural vibrations may be harmful to their operation. This is true even in some cases where the frequency and level of the vibration are so low that they cannot be felt but measured only with sophisticated instrumentation. When a project involves the use of vibration-sensitive equipment, such as electron microscopes, a vibration specialist should always be consulted. The ASHRAE *Systems and Applications Handbook's* Sound and Vibration Control chapter contains guidelines and a table of vibration isolation selections for most common situations.

Space requirements for the isolation springs and equipment bases should be included in the equipment layout. At least 50 mm horizontal and vertical clearance should be provided between all isolated equipment and the building structure. More space is usually preferred for proper access for installation and adjustment.

If equipment can be located in an area which is as stiff as possible, then vibration isolation requirements will be minimized. Equipment which is located on grade is preferred; if that is not possible, then areas above stiff major beams are the second-best location. For standard mechanical equipment, the location is most important for large equipment with a slow rotational speed. For very lightweight mounting surfaces, particularly roof decks, it may be necessary to provide separate framing for the mechanical equipment.

Housekeeping pads are usually provided under all floor-supported equipment. The pads should be connected to the slab with steel dowels. The pad area may be sized to extend beyond the resilient mounts of isolated equipment. These pads are intended to provide local mass and stiffness below mechanical equipment and to keep resilient mounts off the floor, where they may be easily blocked by debris under the spring or equipment bases.

Four basic types of vibration isolators or resilient mounts are resilient pads, elastomeric mounts, steel springs, and pneumatic mounts. Each type has advantages over the others depending upon the degree of isolation required, loadings, flexibility of the supporting structure, and driving frequency.

Resilient Pad Mounts: Resilient isolators are the easiest and most commonly used material. Resilient pad mounts are available in a variety of materials such as ribbed or waffled neoprene and rubber; pre compressed, load-bearing glass fiber; felt foam; and cork. For maximum life and durability, pads of rubber, neoprene, or glass fiber shall be used. Care shall be taken, however, in the selection of the proper material type, density, thickness, and size to ensure that the appropriate loading of the material is achieved. Overloading a resilient pad material causes increased stiffness of the pad and thereby significantly reduces its isolating effectiveness.

Elastomeric Mounts: General-purpose elastomeric mounts typically consist of a resilient material such as neoprene, which can be easily molded into special shapes. These mounts shall be bonded to metal plates and support members of the equipment.

Steel-spring Isolators: The most effective vibration isolating devices available are steel-spring mounts, particularly where large pieces of equipment are involved.

Pneumatic Mounts: Where low-natural-frequency mounts are required, pneumatic vibration isolators shall be used. In this type of mount an elastomer is combined with air to form a rubber/air spring. Pneumatic mounts provide both support and resilience for the equipment mounted on them. By proper sizing and distribution, a very stable, low-profile and low-natural-frequency isolator mount can be obtained with built-in shock overload protection, built-in damping, and in certain cases without the need for external lateral stability provisions.

D.8.9 Equipment Installation

Mechanical equipment with a high power-to-weight ratio shall first be mounted on a concrete inertia base approximately one to two times the weight of the equipment, plus system fluids, if any. The inertia base and equipment shall be resiliently isolated on free-standing, unhoused, stable steel springs and noise isolation pads. Typical pieces of equipment which require concrete inertia bases include fans and chillers over 18.6 kW and pumps and compressors over 3.7 kW. Fan equipment with motors smaller than 18.6 kW shall be mounted on rigid structural-steel frames and the entire assembly mounted on vibration isolators plus noise isolation pads. When the building structural system cannot accommodate the added weight of concrete inertia bases, very high efficiency isolators such as pneumatic mounts shall be used to isolate the equipment mounted on rigid steel frames.

Restraint for lateral and vertical seismic loadings shall be achieved through the use of resilient snubbers which are mounted outboard of the inertia base on the housekeeping pad. The snubbers shall consist of steel angles or brackets bolted to the structure with a layer of resilient material between the inertia base and steel angle. The steel angles and bolts shall be sized by the structural engineer to accommodate the applicable G-force loadings (either static or dynamic) based on the design parameters of each project. Several vibration isolation manufacturers provide isolators which have integral seismic restraint elements built in. However, since inspection of the inside of the units is difficult, they are susceptible to flanking of vibrational energy due to metal-to-metal contact through misalignment.

D.8.10 Steel Spring Isolator Specifications

The most effective vibration isolation system for mechanical equipment involves mounting the equipment plus inertia base or steel frame on freestanding, unhoused, stable-steel springs, with additional travel between solid (fully compressed) height and design height equal to 50% of the static deflection of the spring. Housed-spring units with multiple, small-diameter coils or units with rubber or neoprene cups shall not be used. The horizontal stiffness of the spring isolators shall be specified to be between 0.9 and 1.2 times the vertical stiffness, and the outside diameter of the springs shall be between 0.85 and 1.25 times the operating height of the spring. Each spring shall be equipped with a resilient noise isolation pad between the structure and spring foot. The noise isolation pad shall be precompressed, molded, neoprene-jacketed, load-bearing glass fiber or multiple layers of ribbed or waffled neoprene. For mechanical equipment located on grade, the noise isolation pad shall be minimum of 13 mm thick. At all locations above the grade level the noise isolation pad shall be at least 25 mm thick.

D.8.11 Static Deflections

The static deflections required for vibration isolators are determined by the speed and horsepower of the equipment mounted on them, as well as by the location of the equipment within the building. For this reason it is best to locate as much of the vibrating equipment at grade level as is practicable. All mechanical equipment above grade level shall be located as close as possible to or over a column, load-bearing wall, or other stiff structural member. At above-grade locations the minimum static deflection of any steel spring used to vibration isolate a piece of equipment shall be 25 mm. Fractional horsepower equipment shall be mounted on rubber-in-shear or glass fiber isolators providing at least 13 mm static deflection.

D.8.12 Flanking Transmission

Flanking transmission of vibrational energy from mechanical equipment shall be minimized. All connections to vibrating equipment shall be through flexible connectors, conduits, piping, or hose. All piping in mechanical equipment spaces connected to vibrating equipment shall be supported by resilient ceiling hangers or floor-mounted resilient supports. Penetrations through equipment room walls and ceilings shall be oversized, packed with a resilient material such as glass fiber or mineral fiber, caulked airtight, and covered with escutcheon plates where required for fire ratings. Piping shall be supported on both sides of the penetrations and shall not rest on the structure.

D.8.13 Piping Systems

One of the most common acoustical problems found in buildings is noise generated by the piping systems. Due to its easily identifiable nature, piping noise is one of the most disturbing and offensive types of noises encountered in buildings even though the levels are seldom excessively high. Most of the noise from piping systems is structure-borne, being transmitted along the piping throughout the building where the noise is reradiated as airborne noise.

Piping runs shall be resiliently isolated from the surrounding structure, particularly where the piping runs are located adjacent to acoustically sensitive areas such as conference rooms. Isolating materials shall consist of rubber, neoprene, or spring mounts and felt- or glass fiber-lined sheet metal straps or clamps. At all wall and floor penetration and anchorage points, water piping runs shall be free from the structure and the opening packed with a resilient insulation material and fully caulked. Pipes larger than 50 mm in diameter shall be suspended from the structure on neoprene-in-shear hangers or floor-mounted on resilient supports. Riser piping near critical areas shall be kept free of the structure, and vertical alignment shall be achieved through the use of resilient guides rather than by solid anchorage to the structure. Flexible pipe connectors shall be used to connect the supply and drain pipes to vibrating units such as garbage disposals, pot and pan washers, and dishwashers.

High-pressure steam and water systems are inherently noisy due to turbulence in the fluid flow. To prevent the generation of excessive flow noise cause by turbulent flow in the piping systems located adjacent to sensitive areas, fluid pressure shall be in the range of 276 to 345 kPa. In larger facilities where high-pressure main supply lines are required, pressure regulators shall be used in the supply branches at each floor to maintain the fluid pressure within the above limits. High-velocity flow in the piping system also produces turbulent flow and high noise levels. In piping runs adjacent to acoustically critical areas, such as conference rooms and patient rooms, the maximum flow velocities shall not be exceeded.

The use of short air-filled branch pipes or stubs to control water hammer is not effective since the entrapped air in the stubs gradually dissolves into the water. The most efficient means of preventing water hammer is to install one of the mechanical devices manufactured for this purpose, which employs a gas-filled stainless steel bellows to absorb the shock of the hydraulic waves by mechanical compression of the bellows. These devices are available in a variety of sizes to accommodate most fixture sizes used in buildings. Another method for preventing water hammer in piping systems is to install spring-actuated or relief valves that prevent the instantaneous closure of the valve.

Steam pressure-reducing valves shall be selected for reduced noise generation to meet design criteria. Noise suppressors shall be installed when required. Acoustical attenuation adjacent to reducing station should also be considered.

Electrical conduit connections to all isolated equipment should be made so they do not short circuit the resilient connections. Conduits less than 25 mm in diameter should be made using flexible conduit sections forming a grossly slack connection. Larger-sized connections should be made with manufactured flexible fittings.

Cooling towers on top of buildings should be placed above the roof on an independently supported steel framework. Cooling towers with large, slow propeller fans require vibration isolators with much larger, higher deflection springs than comparably sized towers with centrifugal fans.

For multiple- or variable-speed equipment, the isolator critical frequency should be half of the slowest equipment frequency (rad/s/60). For example, a cooling tower may have a maximum speed of 12 rad/s and a minimum speed of 4 rad/s, or 40 Hz. The isolator critical frequency for that cooling tower should be less than 20 Hz.

D.8.14 Noise Control for Electrical Equipment

Elevators: Both hydraulic and traction elevators may be the cause of disturbing noise and vibration problems and should be evaluated during design. Hydraulic elevators should have the motor/tank/pump assemblies mounted on neoprene isolators that achieve at least 9 mm deflection. Hydraulic piping should be resiliently isolated from the building. Neoprene pad isolators should be used at pipe sleeves, pipe supports, and pipe hangers.

For traction elevators the motor/winch lifting assemblies and motor/generator sets should be isolated from the structure with constrained neoprene isolators that achieve a minimum deflection of 9 mm.

Electrical connections to the isolated equipment should not short-circuit the isolation and should employ flexible conduits or fittings previously noted.

Electric Transformers and Dimmer Banks: Transformers and dimmer banks may be sources for both noise and vibrations. Large utility distribution transformers may be a noise problem in the surrounding community because of the pure tone noise or “hum” associated with them. Smaller distribution transformers inside a building should be isolated from noise-sensitive spaces. Neoprene pads or hangers should be used to attenuate structure-borne vibrations.

Variable-Speed Drives (VSDs): There are three basic types of variable-frequency drives that can be used with HVAC equipment:

- Current-source inverter types
- Voltage-source inverter type
- Pulse-width modulation (PWM) type

The current-source type is usually the quietest.

With voltage-source inverter types, generally the driver units themselves represent the noisiest source. Pulse-width modulation types generally make the motors on the equipment served most noisy while the drive units themselves may be very quiet. For the PWM type, drive units and motors should be compatibly matched.

D.8.15 Community Noise

During design, it is important to realize that noise created by the mechanical systems propagates outside the building, as well as inside. When the site is chosen, the location of nearby noise-sensitive neighbors should be considered. Most often these are residences, but churches, hotels, schools, and dormitories should not be neglected. There may be noise codes which apply and provide specific criteria that may not be exceeded. However, it may be desirable to use a “good-neighbor” policy and keep the noise level at or below the existing ambient condition. That level may be quite low at night, so some judgment must be used in establishing what will be considered satisfactory levels.

There are several types of equipment which may cause noise problems outside a building, as well as inside. The most common are emergency generators, cooling towers, roof fans, rooftop condensing units, etc., which if located outside can be a problem if they are numerous or large enough. An area which is often overlooked is the exterior connection of a laboratory's supply and exhaust fans. These fans are usually quite noisy, and the connections to the outside are generally quite short. It is important to identify significant sources early in design. These noises are most commonly treated with duct silencers or acoustical barriers.

D.9 Mechanical Equipment Location and Access

The Project Engineer shall ensure that all mechanical equipment room layouts are designed to facilitate maintenance access and replacement of system components. Equipment room layouts shall be designed using the largest physical dimensions possible for all specified equipment. All manufacturers specified shall fit within the allocated space. When spacial restrictions and weight restrictions exist in equipment areas, maximum equipment dimensions and weights shall be indicated on the contract documents.

Placement of equipment outside mechanical rooms must permit access from nonrestricted, uncontaminated areas. Systems must be accessible for maintenance 24 hours a day, 7 days a week. Equipment requiring frequent service shall not be installed in occupied rooms or above ceilings in working areas unless it is unavoidable due to space configuration and efforts shall be made to locate them in the traffic areas of the occupied space.

System plenums and casings shall be designed to permit maintenance, cleaning, and replacement of all system components without disassembly of the casing. Fan replacements may be accommodated through removable casing sections. Where possible motors, drives, lubrication devices, valves, traps, etc. shall be located exterior to the plenums and casings for ease of maintenance. In no case shall motors and drives or other components requiring regular service be located within an exhaust airstream.

Easy and safe access to building utilities such as piping, valves, electrical switches, and circuit breaker panels shall be provided. All valves and switches shall be properly identified in accordance with the governing codes and standards.

Systems shall be designed in accordance with the following principles:

- Systems shall be selected with minimal mechanical components requiring service and maintenance.
- System components requiring frequent service and maintenance shall be located in equipment rooms or service areas, and not above suspended ceilings or in occupied spaces.
- Clear and safe access shall be provided for servicing, removal, and replacement of equipment.

- Sufficient instrumentation shall be specified for measuring, indicating, monitoring, and operating at part load as well as full load.

- Equipment shall be selected for long-term durability, reliability, maintainability, and serviceability.

- Equipment shall not be located in confined spaces.

- Main service isolation valves shall not be located close to the mechanical room entrance so that mains may be secured safely in the event of a system failure.

- The building design shall define installation zones for piping, ductwork, conduits, cable trays, and lighting so that access to all serviceable components is clearly defined.

- All environmental room air-conditioning components must be located to accommodate service from outside the plan area of the room. Temperature and humidity sensors may be located within the rooms. Condensing units must not be located directly above the room.

D.10 Systems Identification

A complete identification system shall be provided for all mechanical and electrical components which conforms with the requirements published in ANSI Standard 13.1.

All control devices, i.e. panels, switches, starters, push button stations, relays, temperature controls, etc., shall be clearly identified as to their function and the equipment controlled. All equipment such as pumps, fans, heaters, etc. shall be marked to clearly identify the equipment and space or duty they serve. Equipment shall be identified using engraved laminated black-and-white phenolic legend plates. Letters shall be white on surrounding black at least 19 mm high.

Piping shall be identified with colored, prerolled, semirigid plastic labels set around pipes with a field-installed high-strength cement compound applied along their longitudinal edge. Labels shall be placed around the piping or insulation every 9 m and with one label on each pipe in rooms smaller than 4.5 m. A label shall be placed at every major valve, at least 1.8 m from exit or entrance to an item of equipment, and at each story traversed by the piping system. At the Contractor's option piping concealed above suspended ceilings only may be identified by stenciling with black paint and taped color bands in accordance with the coding system approved by NIH.

Exposed piping in mechanical rooms shall have full-color coding. Fire protection piping shall have full-color coding in all locations.

Labels shall have at least 19 mm high black letters for pipes 25 mm and larger, and 13 mm letters for smaller pipes. All labels shall have flow arrows. Color coding and stencil designations shall be in accordance with the NIH Master Specification 15190 and ANSI Standard 13.1.

Where items requiring routine service are located concealed above ceilings or behind access doors, a suitable and visible label shall be attached to the surface to identify the location of such items.

All valves shall be provided with colored plastic, brass, or aluminum valve tags with stamped-in numbers. Tags shall be secured to the valve with a metal chain. Stop valves on individual fixtures or equipment where their function is obvious, or where the fixture or equipment is immediately adjacent, need not be so equipped. Care shall be exercised in scheduling and selecting valve numbers. The number sequence shall be specific and continuous with individual piping services; i.e., domestic water system valves are always identified as 1.1, 1.2, 1.3, etc., and other distinctly different piping systems shall have another number series. Schematic drawings of each floor shall show the approximate locations, identity, and function of all tagged service and control valves. One copy of each drawing and schedule shall be mounted under glass where directed. A copy of each drawing and schedule shall also be included as a part of the operations and maintenance manuals. Valve tags shall be at least 40 mm round tags with white characters describing the system and valve designation.

Fire protection and fire alarm systems shall be identified as required by NFPA standards and NIH Standard Specifications.

Medical gas piping systems shall be readily identifiable by appropriate labeling with metal tags, stenciling, stamping, or adhesive markers. Color coding shall be used in accordance with CGA Pamphlet C-9 and NFPA Standard 99.

D.11 Piping Systems

This section is intended to define the general installation requirements for the numerous piping systems installed at the NIH. Many codes govern the actual sizing and installation of piping and should be used during the design process. Welding shall conform to current standards and recommendations of the National Certified Pipe Welding Bureau and all OSHA, State fire protection, and NFPA Standard 241 requirements.

Pipe and fittings shall be specified to meet one of the numerous industry standards such as ANSI, ASTM, AWWA, etc. and shall be suitable for the operating temperatures and pressures to be encountered on the project. Pipe stress analysis shall be provided to the NIH by the project engineer when deemed necessary.

Piping and conduits, except electrical conduits run in floor construction, shall be designed to run parallel with the lines of the building. Electrical conduits shall not be hung on hangers with any other service pipes. The different service pipes, valves, and fittings shall be installed so that, after the covering is applied, there will not be less than 13 mm clear space between the finished covering and other work and between the finished covering or parallel adjacent pipes. Hangers on different service lines, running parallel with each other and nearly together, shall be in line with each other and parallel to the lines of the building.

The minimum pipe size shall be 13 mm for plumbing systems, 19 mm for HVAC systems, and 25 mm for fire protection systems. Size reductions may only occur immediately adjacent to equipment connections. Valves and specialties serving equipment shall be full pipe size, not the reduced equipment connection size.

Hangers shall be spaced to prevent sag and permit proper drainage of piping. Hangers shall be spaced not more than 2.4 m apart, unless a greater spacing is specifically designed. A hanger shall be placed within 300 mm of each horizontal elbow.

Vertical runs of pipe and conduit less than 4.6 m long shall be supported by hangers placed 300 mm or less from the elbows on the connecting horizontal runs. Vertical runs of pipe and conduit over 4.6 m long, but not over 18.3 m long, and not over 150 mm in size, shall be supported by heavy steel clamps. Clamps shall be bolted tightly around the pipes and conduits and shall rest securely on the building structure without blocking. Clamps may be welded to the pipes and placed below coupling.

In lieu of individual hangers, multiple (trapeze) hangers should be considered for water pipes having the same elevation and slope and for electrical conduits. Each multiple hanger shall be designed to support a load equal to the sum of the weights of the pipes, conduits, wire, and water, the weight of the hanger itself, plus 90 kg. The size of the hanger rods shall be such that the stress at the root of the thread will not be over 68950 kPa at the design load. No rod shall be smaller than 9 mm. The size of the horizontal members shall be such that the maximum stress will not be over 103425 kPa design load.

Steam, condensate, and other hot service piping shall be designed with loops, bends, and offsets to allow for thermal expansion and keep stresses within the allowable limits of the piping material. Expansion joints or ball joints should be avoided if possible.

Roller-type pipe supports shall be specified where significant horizontal pipe movement will occur due to thermal expansion, and spring-type supports shall be specified where significant vertical movement will occur and where vibration isolation is critical.

Piping shall be designed and installed without due stress or strain and run parallel to the lines of the building, except to grade them as specified in a neat and workmanlike manner using a minimum of fittings. Such fittings, valves, and accessories shall be designed as may be required to meet the conditions of installation and accommodate service. Piping shall be designed to suit the necessities of clearance with ducts, conduits, and other work and so as not to interfere with any passages or doorways and allow sufficient headroom at all places.

Gas-piping systems and other hazardous services shall be designed in strict compliance with applicable codes. Green gas vents, relief valves, rupture disc, etc., shall be piped safely outdoors. Overflow pipes, system drains, and relief devices shall be piped to suitable drainage facilities and indirectly connected. Certain pieces of equipment may have high discharge rates that can quickly result in flooding; drains, sumps, or other receiving devices must have the storage volume required.

Unions and flanges on each side of all pieces of equipment and other similar items, shall be designed in such a manner that they can be readily disconnected. Union flanges shall be placed in a location which will be accessible after completion of the project.

The project engineer shall specify testing procedures for each piping service installed on the project. Test procedures shall include all items required by code and be sufficient to prove all systems tight at conditions which exceed the maximum design conditions. Water sampling to establish a treatment plan, pipeline sterilization, positive pressure, and vacuum testing may be included as part of the procedures.

Pipe and fittings for the NIH buildings shall be as defined in Table No. 3.

Table No. 3

Pipe Assembly

Service		Abbreviation	Color Code	Pipe	Fitting	Joints
1.	Sanitary Drainage	SAN, S, W, V	Green			
a.	Underground and above ground			A	I	a
b.	Above ground within building (optional)			B J	II	b i
c.	Above ground within building (optional)			C B	III II	c e
d.	Vent piping			B	II	b
e.	Vent pipe (optional)			C	III	c
2.	Laboratory/Photo Processing Drainage and Vent	LW, LV LW, LV	Green			
a.	Underground			D	IV	d
b.	Above ground			E	V	e

3.	Biohazardous Waste and Vent	BW, BV	Green			
a.	Underground			F	VI	f
b.	Above ground			G	VII	g
4.	Stormwater and misc. clearwater waste	SW, D	Green			
a.	Underground and above ground			A	I	a
b.	Above ground (optional)			B	II	b
c.	Above ground (optional)			C	III	c
d.	Above ground (optional)			H	VIII	h
5.	Foundation drain	FD	N/A	I	IX	i
6.	Condensate drain	CD	Yellow	C	III	c
7.	All Drainage and Vent Piping above Food Service Areas	N/A	Green	C	III	c
8.	Domestic Cold Water	CW	Green			
a.	Above ground - 65 mm and larger			H	VIII	h
b.	Above ground - 65 mm and larger (optional)			H	X	j
c.	Above ground - 50 mm and smaller			J	XI	k
d.	Underground - 80 mm and larger			K	XII	l
e.	Underground - 65 mm and smaller			L	XI	k
9.	Domestic Hot Water	HW	Yellow			
a.	Above ground - 65 mm and larger			H	VIII	h
b.	Above ground - 65 mm and larger (optional)			H	X	j
c.	Above ground - 50 mm and smaller			J	XI	k
10.	Domestic Hot Water Recirculating	HWR	Yellow			
a.	Above ground - 65 mm and larger			H	VIII	h
b.	Above ground - 65 mm and larger (optional)			H	X	j
c.	Above ground - 50 mm and smaller			J	XI	k
11.	Tempered Water	TW	Yellow			
a.	Above ground - 65 mm and larger			H	VIII	h
b.	Above ground - 65 mm and larger (optional)			H	X	j

c.	Above ground - 50 mm and smaller			J	XI	k
12.	Drinking Water	DW	Green	J	XI	k
13.	Laboratory Cold Water	LCW	Green			
a.	Above ground - 65 mm and larger			H	VII	h
b.	**Above ground - 65 mm and larger (optional)**			H	X	j
c.	Above ground - 50 mm and smaller			J	XI	k
14.	Laboratory Hot Water	LHW	Yellow			
a.	Above ground - 65 mm and larger			H	VIII	h
b.	Above ground - 65 mm and larger (optional)			H	X	j
c.	Above ground - 50 mm and smaller			J	XI	k
15.	Laboratory Hot Water Recirculating	LHWR	Yellow			
a.	Above ground - 65 mm and larger			H	VIII	h
b.	Above ground - 65 mm and larger (optional)			H	X	j
c.	Above ground - 50 mm and smaller			J	XI	k
16.	Animal Drinking Water	ADW	Green	J	XI	k
17.	Chilled Water Supply and Return	CHS/CHR	Green			
a.	700 mm and larger			U	XIII	m
b.	300 mm through 600 mm			T	XIII	m
c.	65 mm through 250 mm			M	XIII	m
d.	65 mm to 125 mm (optional)			M C	XIV	h d
e.	50 mm and smaller			M	XV	j
f.	50 mm and smaller (optional)			J	XI	c
18.	Secondary Chilled Water Supply and Return	SCHS/ SCHR	Green			
a.	300 mm and larger			T	XIII	m
b.	125 mm through 250 mm			M	XIII	m
b.	100 mm and smaller			J	XI	c
19.	Glycol Water Supply and Return	GWS/ GWR	Green			
a.	65 mm and larger			M	XIII	m

b.	65 mm to 125 mm (optional)			M	XIV	h
c.	50 mm and smaller			M	XV	j
d.	50 mm and smaller (optional)			J	XI	c
20.	Condenser Water Supply and Return	CWS/ CWR	Green			
a.	300 mm and larger			T	XIII	m
b.	65 mm through 250 mm			M	XIII	m
c.	65 mm and larger (optional)			M	XIV	h
21.	Cooling Water Supply and Return	CS/CR	Green			
a.	125 mm and larger			M	XIII	m
b.	100 mm and smaller			J	XI	c
22.	Heating Water Supply and Return	HS/HR	Yellow			
a.	300 mm and larger			T	XIII	m
b.	65 mm through 250 mm			M	XIII	m
c.	65 mm and larger (optional)			M	XIV	h
d.	50 mm and smaller			M	XV	j
e.	50 mm and smaller (optional)			J	XI	c
23.	Reheat and Water Supply and Return	RHS/RHR	Yellow			
a.	300 mm and larger			T	XIII	m
b.	65 mm through 250 mm			M	XIII	m
c.	65 mm and larger (optional)			M	XIV	h
d.	50 mm and smaller			M	XV	j
e.	50 mm and smaller (optional)			J	XI	c
24.	Heat Recovery Supply and Return	HRS/HRR	Yellow			
a.	300 mm and larger			T	XIII	m
b.	65 mm through 250 mm			M	XIII	m
c.	65 mm and larger (optional)			M	XIV	h
d.	50 mm and smaller			M	XV	j
e.	50 mm and smaller (optional)			J	XI	c

25.	Secondary Heating Water Supply and Return	SHS/SHR	Yellow			
a.	300 mm and larger			T	XIII	m
b.	125 mm through 250 mm			M	XIII	m
c.	125 mm and larger (optional)			M	XIV	h
d.	100 mm and smaller			J	XI	c
26.	Steam Supply (175 psi Maximum)	HPS/ MPS/LPS	Yellow			
a.	300 mm and larger			T	XIII	m
b.	65 mm through 250 mm			M	XIII	m
c.	50 mm and smaller			M	XVI	j
d.	50 mm and smaller (optional)			M	XVII	m
27.	Steam Relief	SR	Yellow			
a.	65 mm and larger			M	XIII	m
b.	50 mm and smaller			M	XVI	j
c.	50 mm and smaller (optional)			M	XVII	m
28.	Steam Vents	SV	Yellow			
a.	65 mm and larger			M	XIII	m
b.	50 mm and smaller			M	XVI	j
c.	50 mm and smaller (optional)			M	XVII	m
29.	Steam Condensate	HPR/ MPR/LPR	Yellow			
a.	65 mm and larger			N	XIII	m
b.	50 mm and smaller			N	XVI	j
c.	50 mm and smaller (optional)			N	XVII	m
30.	Pump Condensate	PC	Yellow			
a.	65 mm and larger			N	VIII	m
b.	50 mm and smaller			N	XVI	j
c.	50 mm and smaller (optional)			N	XVII	m
31.	Steam Instrumentation	SI	Yellow			
a.	50 mm and smaller			M	XVI	j

b.	50 mm and smaller (optional)			M	XVII	m
32.	Blow Down	BD	Yellow			
a.	50 mm and smaller			M	XVI	j
b.	50 mm and smaller (optional)			M	XVII	m
33.	Feedwater	FW	Yellow			
a.	65 mm and larger			M	XIII	m
b.	50 mm and smaller			M	XVI	J
c.	50 mm and smaller (optional)			M	XVII	m
34.	Makeup Water	MW	Green	J	XI	c
35.	Softened Water	SW	Green	J	XI	k
36.	Distilled Water	DIS	Green	O	XVIII	n
37.	Deionized Water	DI	Green	P	XIX	o
38.	Reverse Osmosis Water Supply and Return	ROS/ROR	Green	Q	XX	p
39.	Oxygen	O	Yellow	R	XI	r
40.	Nitrogen	N	Green	R	XI	r
41.	Nitrous Oxide	NO	Yellow	R	XI	r
42.	Carbon Dioxide	CO	Yellow	R	XI	r
43.	Helium	H	Yellow	R	XI	r
44.	Medical Air	MA	Yellow	R	XI	r
45.	Medical Vacuum	MV	Yellow	R	XI	r
46.	Laboratory Air	LA	Yellow	R	XI	r
47.	Laboratory Vacuum	LV	Yellow	R	XI	r
48.	Gas Evacuation	GE	Yellow	R	XI	r
50.	Fuel Supply	FOS/FOR	Yellow			
a.	65 mm and larger			M	XIII	m
b.	50 mm and smaller			M	XV	j
51.	Fuel Oil Vent	FOV	Yellow	M	XIII	m
52.	Natural Gas	G	Yellow			
a.	65 mm and larger			M	XIII	m
b.	50 mm and smaller			M	XV	j
c.	Underground			S	XXI	s

53.	Compressed Air	A	Blue			
a.	Optional			J	XI	c
b.	Optional			M	XV	j
54.	Control Air	CA	Blue	J	XI	c
55.	Refrigerant Piping	RS/RL HG	Yellow			
a.	65 mm and larger			M	XIII	m
b.	50 mm and smaller			J	XI	t
56.	Refrigerant Relief	RR	Yellow	M	XIII	m
58.	Generator Exhaust	---	N/A	M	XIII	m

Pipe material indicated in Table No. 3 shall be as follows:

	Pipe Specification	Designation
1.	Cast iron hub and spigot pipe, service weight, ASTM A 74	A
2.	Cast iron hubless pipe, service weight, CISPI 301	B
3.	Copper drainage tubing, drain, waste, and vent, (DWV) ASTM B 306	C
4.	High-silicon iron alloy hub and spigot pipe, extra-heavyweight, ASTM A 518, Grade 1	D
5.	Underwriters Laboratories (UL) classified borosilicate glass, ASTM C 1053, FS DD-G-541B, or MIL-P-22561B (YD)	E
6.	Flame-retardant polypropylene acid-resistant drainage pipe, ASTM D 635, Schedule 40	F
7.	Flame-retardant polypropylene acid resistant drainagepipe, ASTM D 635, Schedule 40	G
8.	Galvanized steel pipe ASTM A 53/106 Grade B, seamless, ANSI Schedule 40	H
9.	Porous concrete drain pipe, ASTM C 654 or AASHO M-176	I
10.	Seamless copper water tube, ASTM B 88, Type K, hard	J
11.	Ductile iron water pipe, outside coated, AWWA C 104/A 21.4 cement mortar-lined, ANSI/AWWA C 151/A 21.51 pipe	K
12.	Seamless copper water tube, ASTM B 88, Type K, soft	L
13.	Black steel pipe, ASTM A 53/106 Grade B, seamless Schedule 40	M
14.	Black steel pipe, ASTM A 53/106 Grade B, seamless Schedule 80	N

15.	As required by program of requirements and required water quality	O
16.	Polypropylene pipe, Type 11 copolymer, ASTM D 4101	P
17.	As required by program of requirements and required water quality	Q
18.	Seamless copper water tube, ASTM B 88, Type K, hard, prepared and labeled for oxygen service and sealed when delivered to the site	R
19.	Polyethylene pipe, ASTM D 2513, 690 kPa working pressure, standard dimension ration (SDR), the ratio of pipe diameter to wall thickness, 11.5 maximum	S
20.	Carbon steel pipe, extra heavy wall (seamless) Type XS ASTM A 53/ 106 Grade B	T
21.	Carbon steel pipe, double submerged arc welded longitudinal seam, ASTM A 53/ 106, Grade B	U

Fitting materials indicated in Table 3 shall be as follows:

Fitting Specification

Designation

1.	Cast-iron hub and spigot fittings, service weight, ASTM A 74	I
2.	Cast-iron hubless fittings, service weight, CISPI 301	II
3.	Wrought copper and bronze drainage fittings, ANSI Standards B16.23, ANSI/ASMEB16.29 or ANSI/American Society of Mechanical Engineers (ASME) B16.32	III
4.	High-silicon/iron alloy hub and spigot fittings extra-heavyweight, ASTM A 518, Grade 1	IV
5.	UL-classified borosilicate glass drainage fittings, ASTM C1053, FS DD-G-541B, or MIL-P-22561B	V

(YD)

6.	Enfusion joint flame-retardant polypropylene acid-resistant drainage fittings, ASTM D635	VI
7.	Flame-retardant, polypropylene acid-resistant, mechanical joint-type drainage fittings, ASTM D 635	VII
8.	Galvanized steel grooved-end fittings, and couplings, ASTM A 47M or ASTM A 536	VIII
9.	Porous concrete drainage fittings, ASTM C 654 or AASHO M-176	IX
10.	Galvanized malleable cast-iron screwed fittings, ANSI Standard B16.3, 68 kg for less than 517 kPa and 517 kPa or more	X
11.	Wrought-copper solder joint fittings, 68 kg, ANSI Standard B 16.18 or ASME/ANSI B16.22 and ASTM B 4 copper pipe nipples with threaded end connections	XI
12.	Ductile iron pressure fittings, AWWA C 110/A 21.10, 1724 kPa	XII
13.	Steel butt-welding fittings, ANSI Standard B 16.9 using long-turn ells, ANSI Standard B 16.5 weld-neck or slip-on flanges and Bonney Forge Woodlets and threadolets, wall thickness to match pipe	XIII
14.	Black, malleable iron-grooved fittings and couplings, ASTM A 47.	XIV
15.	Black, malleable iron-screwed fittings, 68 kg, ANSI Standard B 16.3 for less than 517 kPa and 136 kg for 517 kPa.or more	XV
16.	Black, cast-iron screwed fittings, ANSI Standard B16.4, 57 kPa less than 517 kPa and 113 kg for 517 kPa and more. Steam and condensate piping shall be 113 kg for all operating pressures	XVI
17.	Black steel socket wire fittings, ANSI Standard B 16.11 wall thickness to match pipe	XVII

18.	As required by program of requirements and required water quality	XVIII
19.	Polypropylene long-radius or DWV fittings, Type II copolymer, ASTM D 4101.	XIX
20.	As required by program of requirements and required water quality	XX
21.	Polyethylene socket fittings, ASTM D 2683 or butt-fusion fittings, ASTM D 2513 molded	XXI

Joint materials indicated in Table No. 3 shall be as follows:

	Joint Specification	Designation
1.	Premolded rubber compression gasket joint, ASTM C 564 or CISPI HSN	a
2.	No-hub neoprene gasket and stainless steel corrugated shield, CISPI 310 coupling	b
3.	Soldered using ASTM B 32, 95-5 tin-antimony or Grade Sn 96 tin-silver and flux containing not more than 0.2% load	c
4.	Acid-resistant packing and molten lead-filled hub	d
5.	Glass-to-glass connection with compression-type bead-to-bead and bead-to-plain end couplings	e
6.	Enfusion joint with maximum average burn time of 80 sec. and maximum extent of burning of 20 mm in accordance with ASTM D 634	f
7.	Mechanical joints and adapters, connections containing EVA components are prohibited	g
8.	ASTM A 183 coupling nuts and bolts, ASTM D 2000 rubber gaskets for water service	h
9.	Tongue and groove joints sealed with mortar	i

10.	Threaded using American Standard for pipe threads, ANSI Standard B 2.1	j
11.	Soldered using ASTM B 32, 95-5 tin-antimony or code-approved lead-free solder	k
12.	AWWA C11/A21.11 rubber gasket joint for mechanical-joint, ductile iron pressure pipe and fittings	l
13.	Welded engineering standards of the Mechanical Contractors Association of America, Inc. Part VII, Standard Procedure Specifications 1 and 2	m
14.	As required by program of requirements and required water quality	n
15.	Butt-fusion technique per ASTM D 2657, Section 9	o
16.	As required by program of requirements and required water quality	p
17.	Brazed: AWS A5.8 BCuP (brazing-copper-phosphorus) series, greater than 538° C melting temperature, cadmium-free brazing filler; the use of flux is prohibited	r
18.	Fusion of welded joints using electrically heated tools, thermostatically controlled and equipped with temperature indication.	s
19.	Brazed: AWS A5.8 brazing filler metal Type BAg-5 with AWS Type 3 flux, except Type BcuP or BCuP-6 maybe used for brazing copper-to-copper joints	t

* “q” not used

Methods and materials for wet taps, where permitted by NIH, shall be submitted for approval by the A/E. Submittals shall include documentation on the products to be used with complete instructions and procedures to insure a successful wet taps.

D.12 Insulation Systems

Insulation shall be applied to mechanical systems to limit heat loss, prevent condensation, protect people from hot or extremely cold surfaces, and improve the operating efficiency of all systems. The value of proposed insulation systems shall be justified by comprehensive life cycle costing and present-worth analysis.

Insulation materials approved for use in the NIH buildings shall have a fire hazard rating not to exceed 25 for flame spread and 50 for fuel contributed and smoke developed. All materials shall be factory tested as an assembly. Fire ratings shall be determined by the standard method of testing for surface-burning characteristics of building materials, ASTM E-84 or NFPA Standard 255. Insulation approved for use shall have a UL label or a certified test report from an approved testing laboratory.

Insulation materials shall not be installed on systems until all necessary tests have been conducted and insulated surfaces have been thoroughly cleaned and are in a dry state.

All adhesives, sealers, vapor barrier coatings, etc. used in conjunction with insulation shall be compatible with the material to which they are applied. Any cement, sealer, or coating used shall be resistant to vermin and mold and shall be durable.

All insulation surfaces shall be durable and, where exposed, protected from damage due to maintenance operations, vandalism, weather, and normal wear and tear. Protective jackets consisting of 0.23 kg canvas or 0.41 mm aluminum shall be used for exposed insulation systems.

Pipe fittings and valves, where possible, shall be protected using factory-premolded fittings covers and factory-protect insulation. Large valves and specialties shall be protected using custom-made canvas jackets with straps and buckles to allow frequent removal and reinstallation without damaging the jacket.

Metallic components used for the installation of insulation systems shall be suitable for the intended environment and shall not corrode. Exposed external corners on duct and equipment insulation in occupied areas shall be protected by corner beads consisting of 50 mm by 50 mm by 0.41 mm thick aluminum.

Insulation systems shall be specified to meet industry standards, and installation requirements shall, as a minimum, include the following:

- Insulation shall be continuous at all hangers, hanger rods, supports, sleeves, and openings. Vapor seals must be provided for all cold surfaces and shall be continuous. Where supports must occur below insulation surface, the thickness shall be maintained over the support and extend sufficiently beyond the support to prevent condensation. Insulation shall be sealed where it terminates because of a valve, union, flange, etc.

- All insulation shall be arranged to permit expansion and contraction of systems without causing damage to the insulation or surface

- The actual insulation thickness must be at least equal to the minimum specified at all locations, including supports in contact with cold surfaces

- It is critical that insulation materials be installed in a first-class manner with smooth and even surfaces. Scrap pieces of insulation shall not be permitted where a full-length section will fit

- High-density pipe saddles or welded pipe standoffs shall be provided at all points of pipe support

- All valves and strainers shall be insulated, and premolded covers and factory-precut insulation or custom-fabricated jackets shall be used where applicable. Unions and flanges shall not be insulated except on cold services.

- Valves shall be insulated up to and including bonnets, except for cold water valves, which shall be insulated over packing nuts in a manner to permit removal for adjustment and repacking

- Strainers shall be insulated to permit removal of the basket without disturbing the insulation of the strainer

- On ductwork or equipment, accessories shall be provided as required to prevent distortion and sagging of insulation. Welded pins, adhesive clips, and wire ties shall be provided as recommended by the manufacturers.

- Duct and equipment insulation shall cover all standing seams and metal surfaces with full-thickness insulation

- Cold water pumps shall be insulated with removable and replaceable square or rectangular covers consisting of full 1.3 mm gauge aluminum metal jackets reinforced at corners and edges and lined with insulation. Pumps with split casings shall be constructed with insulated housing in two or more sections with the upper section removable for access to the casing. Cover sections shall be flanged, gasketed, and joined with stainless steel sheet metal screws. Lube fittings and drain valves shall extend outside of insulated covers

- Where deemed necessary by the A/E, specific insulation details shall be added to the Contract documents to improve the insulation performance on the project

<u>Insulation may be omitted on the following items at the discretion of the A/E:</u>

- Brass or copper pipe specified to be chrome plated (typically applies to toilet rooms)

- Traps and pressure-reducing valves, concealed relief piping from safety valves, and unions, flanges, and expansion joints on hot piping systems

- All fire protection and fuel piping

- Exposed ducts in air-conditioned spaces

- Existing adjacent insulation

- ASME stamps

- Access plates of fan housings

- Cleanouts or handholes

- Components within factory-preinsulated HVAC equipment

- Factory-preinsulated flexible ductwork

- Factory-preinsulated HVAC equipment
- Manufacturer's nameplates
- Vibration-isolating connections

Tables Nos. 4-9 define the minimum insulation standards for NIH projects and are intended as a guide for the services listed and other similar services not indicated. The A/E shall select the most suitable product for each individual service.

Table No. 4
Insulation Material for Piping

Service	Material	Spec.	Type	Class	Vapor Barrier Required
Chilled Water (Supply & Return, Dual Temperature Piping, 4oC nominal)	Cellular Glass	ASTM C 552	II	2	Yes
	Urethane	ASTM C 591			Yes
Hot Domestic Water Supply and Recirculating Piping (Maximum 93oC)	Cellular Glass	ASTM C 552		2	No
	Urethane	ASTM C 591	II		Yes
Cold Domestic Water Piping Above & Below Ceilings	Cellular Glass	ASTM C 552		2	Yes
	Urethane	ASTM C 591	II		Yes
Heating Hot Water (Supply & Return, Maximum 121oC)	Calcium Silicate	ASTM C 533	I		No
	Cellular Glass	ASTM C 552	II	2	No
Refrigerant Suction Piping (177oC nominal)	Flexible Cellular	ASTM C 534	I	1	Yes
	Mineral Fiber	ASTM C 547			Yes
Compressed Air Discharge, Steam and Condensate Return (94 to 121oC)	Cellular Glass	ASTM C 552	II		No
	Mineral Fiber	ASTM C 547		1	No
	Calcium Silicate	ASTM C 533	I		No
Drinking Fountain, Drain Piping (to sewer tie-in)	Mineral Fiber	ASTM C 547		1	Yes
	Cellular Glass	ASTM C 552	II	2	Yes
	Flexible Cellular	ASTM C 534	I		Yes
Exposed Lavatory Drains, Exposed Domestic Water Piping & Drains to Areas for Handicapped Personnel	Flexible Cellular	ASTM C 534	I		No

Horizontal Roof Drain Leaders (Including Underside of Roof Drain Fittings)	Mineral Fiber	ASTM C 553	I	B-3	Yes
A/C Condensate Drain Located Inside Bldg.	Mineral Fiber Cellular Glass Flexible Cellular	ASTM C 547 ASTM C 533 ASTM C 534	 II I	1 2	Yes Yes Yes
Medium-Temperature Hot Water, Steam and Condensate (122 o to 177o C)	Calcium Silicate Cellular Glass	ASTM C 533 ASTM C 534	 I I or II		No No
High-Temperature Hot Water and Steam (371o C to 371o C) Composite	Calcium Silicate Mineral Fiber/Cellular Glass	ASTM C 533 ASTM C 547 & ASTM C 552	 I		
Brine Systems Cryogenics (- 30o to 0oC)	Cellular Glass	ASTM C 552	II	2	Yes
Brine Systems Cryogenics (0o to 34o C)	Cellular Glass	ASTM C 552	II	2	Yes

Table No. 5
Piping Insulation Thickness (millimeters)

Service	Material	Tube and Pipe Size (millimeters)				
		6-32	40-80	90-125	150-250	280-400
Chilled Water (Supply & Return) & Dual Temperature Piping) (4oC Nominal)	Cellular Glass Cellular Glass Urethane	40 40 20	50 40 20	50 40 20	65 40 25	80 40 25
Hot Domestic Water Supply and Recirculating Piping (Maximum 93oC)	Cellular Glass Urethane	40 20	40 20	40 25	40 25	40 25
Cold Domestic Water Piping Above & Below Ceiling	Cellular Glass Flexible Cellular Urethane	40 15 20	40 15 20	40 15 20	40 N/A 25	40 N/A 25
Heating Hot Water (Supply & Return, Maximum 121oC)	Calcium Silicate Cellular Glass	50 40	50 40	65 40	65 40	65 40
Refrigerant Suction Piping (177oC)	Flexible Cellular Cellular Glass	15 40	N/A 40	N/A 40	N/A 40	N/A 40
Compressed Air Discharge, Steam and Condensate Return (94oC to 121oC)	Mineral Fiber Calcium Silicate Cellular Glass	40 50 40	50 80 40	65 100 40	80 100 40	90 115 40

Exposed Lavatory Drains, Exposed Domestic Water Piping & Drains to Areas for Handicapped Personnel	Flexible Cellular	15	15	15	16	16
Horizontal Roof Drain Leaders (including Under side of Roof Drain Fitting)	Mineral Fiber	25	25	40	40	50
A/C Condensate Drain Lo cated Inside Bldg.	Mineral Fiber Cellular Glass Flexible Cellular	20 40 15	25 40 15	25 40 15	25 40 N/A	25 40 N/A
Medium-Temperature Hot Water and Steam (122oC to 177oC)	Calcium Silicate Celluar Glass	65 40	90 40	115 40	115 50	125 65
High-Temperature (177ooC to 204oC) and Steam (177oC to 260oC)	Calcium Silicate Cellular Glass Composite	65 25 50	80 25 50	100 25 50	100 25 50	100 25 50
Brine Systems Cryogenics (- 34oC to OoC)	Cellular Glass	65	65	80	80	90
Brine Systems Cryogenics (0oC to 171oC)	Cellular Glass	50	50	50	65	80

Table No. 6
Minimum Duct Insulation Thermal Resistance Factors

DELTA t oC	R
27	1.8
54	3.6
81	5.4
108	7.2
136	9.1
162	11.1

NOTE: Duct systems, or portions thereof, shall be insulated to provide a thermal resistance, excluding film resistances, of

R = DELTA t m2hoC/Joules)
15

Where DELTA t = design temperature differential between air in the duct and the duct surface in degrees Fahrenheit. Noninsulated ducts in noninsulated sections of exterior walls and in attics above the insulation might not meet requirements of ASHRAE Standard 90A. Required thermal resistances do not consider condensation. Additional insulation with vapor barriers may be required to prevent condensation under some conditions. For residential buildings with uninsulated roofs over attics containing ducts, air temperatures shown in Table 6A shall be used.

Excerpted by permission from ASHRAE Standard 90A, published by American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA.

Table No. 6A
Residential Attic Temperature

Roof Pitch: Summer Conditions	Degrees Celsius
5 in 12 and up	54
3 in 12 to 5 in 12	60
Less than 3 in 12	66
Roof Pitch: Winter Conditions	
All Roof Pitches	-12 over Outdoor Design

Excerpted by permission from ASHRAE Standard 90A, published by American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA.

Table No. 7
Insulation Materials for Equipment

Equipment	Spec.	Type	Class
Flexible Mineral Fiber Surface Temperatures up to 204oC	ASTM C 553	I	B-3
Rigid Mineral Fiber	ASTM C 612		
Surface Temperatures up to 204oC			1 or 2
Surface temperatures up to 454oC			3
Cellular Glass Surface Temperatures between -240oC and + 427oC	ASTM C 552	1, 2 or 3	1 or 2

Table No. 8
Insulation Thickness for Equipment (millimeters)

Equipment	Recommended Thickness
Expansion Tanks or Pneumatic Water Tanks	25
Air Separators	50
Pumps	50
Hot Water Storage Tanks	50
Heat Exchangers, such as Steam-to-Hot-Water Convertors	
Up to 121oC	50
121 to 204oC	90
205 to 316oC	150
Hot Water Duct-Mounted Coils	50
*Chilled Water Tanks 177oC to 13oC	25
*Cryogenic Equipment Minus 34oC to minus 17oC	100

NOTE: * Vapor barrier is required.

Table No. 9
Insulation and Thickness (millimeters) for Boiler Stack and Diesel Engine Exhaust Pipe

Service & Surface Temperature Range (Degrees C)	Materials	Outside Diameter (millimeters)				
		6-32	40-80	90-125	150-250	280-900
Boiler Stack (Up to 204)	Mineral Fiber ASTM C 553, Class B-3, ASTM C 547, Class 1, or ASTM C 612, Class 1	N/A	N/A	80	90	100
	Calcium Silicate ASTM C 533, Type 1	N/A	N/A	80	90	100
	Cellular Glass ASTM C 552, Type II	40	40	40	50	65

Boiler Stack (205 to 316)	Mineral Fiber ASTM C 547, Class 2, ASTM C 592, Class 1 or ASTM C 612, Class 3	N/A	N/A	100	100	125
	Calcium Silicate ASTM C 533, Type 1	N/A	N/A	100	100	100
	Mineral Fiber/Cellular Glass Composite:					
	Mineral Fiber ASTM C 547, Class 2 ASTM C 592, Class 1 or ASTM C 612, Class 3	25	25	25	25	50
	Cellular Glass ASTM C 552, Type II	50	50	50	50	50
Boiler Stack (316 to 427)	Mineral Fiber ASTM C 547, Class 3 ASTM C 592, Class 1 or ASTM C 612 Class 3	N/A	N/A	100	100	150
	Calcium Silicate ASTM C 533, Type 1	N/A	N/A	100	100	150
	Mineral Fiber/ Cellular Glass Composite:					
	Mineral Fiber ASTM C 547, Class 2 ASTM C 592, Class 1 or ASTM C 612, Class 3	50	50	50	80	100
	Cellular Glass ASTM C 552, Type II	50	50	50	80	50
Diesel Engine Ex haust (Up to 371)	Calcium Silicate ASTM C 533, Type I	80	90	100	100	100
	Cellular Glass ASTM C 592, Type II	65	90	100	115	150

D.13 Testing and Balancing (T&B)

The A/E for NIH buildings shall specify a complete and comprehensive total-system balance process that includes testing, adjusting, and balancing of environmental and other systems to produce the design objectives. Air conditioning as defined by ASHRAE is the process of treating air to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the comfort requirements of the conditioned space. The balance process serves as the quality control function to insure that the air-conditioning systems are performing to the specified design intent.

Each air treatment process in the conditioning system contributes a specific function to produce proper environmental conditions. However, it is the coordinated action of all these processes in a system that produces the desired effect. If any one of these coordinated functions does not perform to expectations, the final results will affect the overall system performance. The balancing process must confirm that the entire system produces the results for which it was designed.

The T&B process shall be specified to meet the National Standards for Total System Balance as defined by the Associated Air Balance Council's (AABC) latest edition. All work provided must be performed by an independent T&B contractor who is an approved member of the AABC. The T&B contractor shall provide all required preconstruct ion plan checks and reviews; shall test, adjust, and balance the air and water system for the project; and shall submit completed reports, analysis, and verification data showing system performance that satisfies contract requirements.

T&B is a science that requires the proper use of instruments, evaluation of readings, and adjustment of the system to design conditions. The mere ability to use an instrument does not qualify a person as a T&B engineer or technician. Qualification requires training and years of field experience in applying proven techniques and in analyzing gathered data. Project specifications shall require that only certified engineers and technicians be allowed to test and balance systems in NIH buildings.

NIH building projects oftentimes are constructed and occupied in multiple phases. The T&B process specified shall address the requirements of interim balancing to support partial occupancy of buildings. The health and safety of occupants and the environmental conditions must be suitable for continuous operation at all phases during construction.

Mechanical systems may require complete or zone balancing at the end of each phase. Once fully occupied, entire systems may require reverification to ensure that later phases have not created deficiencies in early ones. Multiple drive assemblies may be required for fans. Follow-up T&B work may also be required during premium time to avoid disruption in research functions.

The completion of T&B services seldom occurs smoothly because of construction problems and occupancy functions. The A/E, Project Officer, and research staff should develop an occupancy plan and operation strategy that can be specified in the Contract documents and force the T&B process to accommodate. The Project Engineer's task will be to define a generalized T & B procedure that fully supports the phasing and clearly ties down the full scope of work at bid time. All cost associated with T&B services through the completion of building occupancy should be included at bid time.

D.14 Program Equipment

The selection and use of program equipment such as refrigerators, freezers, centrifuges, autoclaves, ware washers, flow cabinets, etc. shall be established early in the design phase so that mechanical systems can be designed to support specific equipment requirements. All equipment selected for use in NIH facilities shall meet NFPA requirements and NIH Division of Safety Data Guidelines.

The A/E shall carefully ascertain equipment requirements so that heat rejection, electrical usage, and other utility consumption data are defined for system design. Spatial requirements for equipment must be closely reviewed, and layouts shall allow for access to all piping, wiring, and ductwork connections. Mechanical systems shall be designed and detailed so that they do not induce harm to or impede the operating efficiency of program equipment. Pressure regulators, safety relief valves, gravity drainage facilities, temperature controls, and backflow protection devices shall be provided as required to protect equipment.

Program equipment as defined by the program of requirements shall be connected to building energy management and control system to monitor integral equipment alarms. The complete control and operation/maintenance strategy for program equipment shall be closely reviewed against program requirements and with building occupants. The maintenance of such equipment often dictates the magnitude of control points and monitoring facilities.

D.15 Motors and Drives

Motors and drive assemblies shall be selected to optimized the efficiency of mechanical and building systems. Motors must always be of adequate size to drive the equipment without exceeding the nameplate rating at the speed specified or at the load which may be obtained by the drive.

Motors shall be rated for continuous duty at 115% of rated capacity and base temperature rise on an ambient temperature of 40°C.

Motors 560 W and larger shall be three-phase, Class B, general-purpose, squirrel cage, open-type, high-efficiency induction motors in accordance with National Electrical Manufacturers association (NEMA) design B standards, wound for voltage specific to the project, 60 Hz AC, unless otherwise required by the design. Motors smaller than 560 W shall be single-phase, open-capacitor type in accordance with NEMA standards for 115 V, 60 Hz, AC., Motors 124 W and smaller may be the split-phase type.

All motors utilized on NIH projects shall have the minimum efficiency as scheduled below. Nameplate rating and efficiency shall be per Institute of Electrical and Electronics Engineers (IEEE), Test Procedure 112, Method B:

Motor Size (Kilowatts)	Minimum Required Efficiency (%)
0.75	82.5
1.1- 1.5	84.0
2.2 -3.7	87.5
5.6 -7.5	89.5
11.2-14.9	91.0
18.7 -22.4	92.4
29.8-37.3	93.0
44.8	93.6
56.0	94.1
74.6-93.3	94.5
112.0-149.2	95.0

All motors 1 hp and larger shall have a composite power factor rating of 90% to 100% when the driven equipment is operating at the design duty. Devices such as capacitors, or equipment such as solid-state power factor controllers, shall be provided as part of the motor or motor-driven equipment when required for power factor correction.

VSDs of various types will be employed on NIH projects to vary the flow of water and air. The A/E shall evaluate the specific application of each speed drive and provide life cycle costing to prove its economic viability. Other variable-flow devices such as inlet vanes may be considered for smaller systems.

The A/E shall consider the following issues when employing VSDs for NIH buildings:

- When main and standby equipment is to be controlled by speed drives, only one drive shall be provided to serve both pieces of equipment.

- Equipment motors shall be matched to the drive so that low speeds can be realized.

- Speed drives shall have a manual bypass completely independent of the drive cabinet. Motors shall operate at full speed in the bypass position when the speed drive is deenergized and open for service.

- When deemed necessary due to the critical nature of equipment served, multiple drives may be provided for redundant equipment.

- The level of reliability required of the VSD system shall be identified.

- The operational overloads and starting conditions required by the application shall be defined. Typical requirements may be: variable torque = 115% for 1 min., constant torque = 150% for 1 min.

- The way control commands for the VSDs will be generated by the process shall be determined, i.e.:
  Manual/potentiometer Analog current loop, 4-20 mA
  Serial communication (RS232, RS485, etc.) Isolated or nonisolated
  Process feedback (pressure, temperature, flow, etc.)

- The characteristic surges, sags, or momentary discontinuities present in the supply and any other nonlinear loads on the feeder shall be defined.

- The levels of voltage distortion on the power system shall be determined before the VSD is applied; what harmonic current spectrum will be injected into the supply system by the VSD; what the magnitude of distortion is on the supply voltage before and after; and whether this harmonic current injection will affect other loads shall be defined.

- The levels of voltage on the power system before the VSD is applied; what harmonic current spectrum will be injected into the supply system by the VSD; what the magnitude of distortion is on the supply voltage before and after; and whether this harmonic current injection will affect other loads shall be defined.

- What speed range is required and whether the load will be operated beyond base speed range shall be defined.

- It shall be determined if all parts of the rotating load are suitable for the range of vibration excitation frequencies.

- The waveform the VSD produces and whether there are any constraints on the motor connections length shall be determined.

- It shall be verified that the motor is sized to provide the necessary load torque while operating at reduced speed. The power capability of the motor may be restricted at low speeds. The motor output capability shall be compared with the load requirement. An additional cooling fan may be required for constant torque loads. (This pertains to constant torque systems, such as compressors, etc.)

- The heat rejection from the VSD controller and how the losses are removed from the equipment shall be defined. The heat generated with the VSD is normally removed by air or water cooling.

- The range of voltage and frequency of the electric supply that will permit full rated output of the VSD shall be defined. What happens outside the range, what line transients can be tolerated, and what the VSD input power factor is shall be considered.

- How the VSD operates under fault conditions shall be defined; for example, a mechanical overload, an electrical short circuit in the motor circuit, or a ground fault in the load system.

- The motor protection provided by the VSD equipment and any additional protection required for comprehensive system protection, e.g., overload, overspend, reverse rotation, shall be defined.

- The manufacturer shall be required to submit information for system operations and maintenance and to sell diagnostic, warranty, training, and operation and maintenance manuals.

- The total power factor (PF) (i.e., real PF and apparent PF) shall be defined. The difference between the two is caused by inductance (reactive element) in transformers, motors, etc.

D.15.1 Harmonic Voltage and Currents

VSDs inject harmonic currents into the power system due to the nonlinear nature of switching in electronic power devices. The harmonic currents combine with the system impedance frequency response characteristic and create harmonic voltage distortion. The harmonic voltages and currents can cause spurious operation of Potomac Electric Power Company (PEPCO) and NIH relays and controls, capacitor failures, motor and transformer overheating, and increased power system losses. These problems are usually compounded by the application of power-factor correction capacitors (especially on the NIH's low-voltage system), which can create resonance conditions that magnify the harmonic distortion levels. Several concerns associated with harmonic distortion levels need to be addressed in the project specification. This will avoid significant harmonic-related problems with both the VSD equipment and the NIH operations controlled. These concerns include the following:

- Harmonic distortion on both the supply and motor side of the drive

- Equipment derating due to harmonic distortion produced by VSDs

- Audible noise caused by high-frequency (several kilohertz) components in the current and voltage

- Harmonic filter design and specifications

A three-phase VSD system consists of three components (rectifier, direct-current (DC) link, and inventer) and a control system. The rectifier converts the three-phase 60 Hz AC input to a DC signal. Depending on the system, an inductor, a capacitor, or a combination of these components smooths the DC signal (reduces the voltage ripple) in the direct current link. The inventer circuit converts the DC signal into a variable-frequency AC voltage to control the speed of the induction motor. Since for this application a voltage-source inventer (VSI) drive is considered, the concern regarding this particular device is outlined below. These drives (the most common types, up to 300 hp) use a large capacitor in the DC link to provide relatively consistent DC voltage to the inventer. The inventer then chops this DC voltage to provide a variable-frequency AC voltage for the motor. VSI drives can be purchased off the shelf and employ PWM techniques to improve the quality of the output voltage waveform. However, there is a concern regarding nuisance tripping due to capacitor-switching transients. Small VSDs have a VSI rectifier (AC to DC) and use a PWM inventer (DC to AC) to supply the motor. This design requires a DC capacitor to smooth the DC link voltage. The controls for this type of drive have protection for DC overvoltages and under voltages with narrow thresholds. It is not uncommon for the DC over voltage control to cause tripping of the drive whenever the DC voltage exceeds 1.17 per unit (for the particular application, 760 V for a 480-V application). Since the DC capacitor is connected alternately across each of the three phases, drives of this type can be extremely sensitive to overvoltages on the AC power side. One event of particular concern is capacitor switching on the PEPCO system. PEPCO voltage-switching transients result in a surge of current into the DC link capacitor at a relatively low frequency (300-800 Hz). This current surge charges the DC link capacitor, causing an over voltage to occur (through Ohm's law). The overvoltage (not necessarily magnified) exceeds the voltage tolerance thresholds associated with the overvoltage protection, which most likely will trip the VSD out of service. This is called nuisance tripping because the situation can occur day after day, often at the same time. Several methods are available to ameliorate such tripping; some are simple, and some costly. Use of harmonic filters to reduce overvoltages, an expensive alternative, is effective in protecting drives from component failure but may not completely eliminate nuisance tripping of small drives. The most effective (and inexpensive) way to eliminate nuisance tripping of small drives is to isolate them from the power system with series inductors (chokes). With a concomitant voltage drop across the inductor, the series inductance of the choke(s) reduce(s) the current surge into the VSD, thereby limiting the DC overvoltage. The most important issue regarding this method is that the designer should determine the precise inductor size for each particular VSD; this requires a detailed transient simulation that takes into account capacitor size, transformer size, etc. The choke size must be selected carefully. If the choke has too much impedance, it can increase harmonic distortion levels and notching transients at the drive terminals. Chokes for this application are commercially available in sizes from 1.5% to 5.0% of the VSD impedance at various hp ratings. A size of 3.0% is sufficient to avoid nuisance tripping due to capacitor-switching operations. Standard isolation transformers serve the same purpose.

D.15.2 Voltage Sag Concerns

Despite the main advantages provided by VSDs, the concern for nuisance tripping during voltage sag conditions remains. This power quality concern involves the control sensitivity to short-duration voltage sags and momentary interruptions. Actually, many different kinds of controls, and even motor contractors, are sensitive to these voltage sags. Therefore, voltage sags caused by faults on the power system represent one of the most important problems that can be experienced by the NIH with sensitive loads. Whenever there is a fault on the transmission or distribution system serving the NIH facility (faults cannot be completely avoided regardless of the system design), there will be either a voltage sag or an interruption. If the fault occurs on a parallel-distribution feeder circuit or on the transmission system, there will be a voltage sag that lasts until the fault is cleared by some protective device (typically 3-30 cycles depending on the fault location). A method of predicting the likelihood of faults in a certain region along with knowledge of equipment sensitivity can be used to determine an “area of vulnerability.” A combination of computer short-circuit simulations and lightning performance analysis should be used to determine the affected area. The VSD controls should be designed to handle these voltage sag conditions without tripping. The specifications contain no-ride-through capability. This is an important consideration when VSDs are applied in critical processes such as that of the NIH, where nuisance tripping can cause significant problems. The designer should evaluate the level of sensitivity of the controls to voltage sags. If such concern exists, applying power conditioning to the controls themselves will be considered. Feroresonant transformers can handle voltage sags down to approximately 60% of the nominal voltage. This is sufficient to handle virtually all voltage sags caused by single line-to-ground faults on the power system. If additional protection is needed, the controls can be protected with an uninterruptible power supply (UPS) system, which can handle complete interruptions in the input signal.

D.15.3 Transient Overvoltage Concerns

Transient overvoltages occur in connection with capacitor switching. Each time a capacitor is energized, a transient voltage oscillation occurs between the capacitor and power system inductance. The result is a transient overvoltage that can be as high as 2.0 per unit (of the normal voltage) at the capacitor location. The magnitude is usually less than 2.0 per unit due to dampening provided by system loads and losses. The transient overvoltages caused by capacitor energizing are generally not a concern to PEPCO because their magnitude is usually below the level at which surge-protective devices operate (1.5-2.0 per unit). However, these transients can be magnified at the NIH facility if the NIH has low-voltage capacitor banks for (displacement) power factor correction. (The designer should check for this matter.) When the frequency of a transient over voltage matches the series-resonant frequency of the NIH's transformer coupled with PEPCO capacitor(s) at the East Substation, a low-impedance, high-current (at the resonant frequency) condition results. As this large current passes through the NIH's transformer, it induces a large voltage “drop” that passes through zero voltage to create a large voltage of opposite sign (because of a phase-angle change) at the resonant frequency. The VSD and the NIH's paralleled capacitor (and their surge protection devices) then see this magnified voltage (compared to distribution feeder voltage). When the resonant-frequency current completes its path to ground through the capacitor, the voltage experiences a “boost” to the ground-reference voltage. The magnification of capacitor-switching transients is most severe when the following condition exists: The capacitor switch on the higher voltage system is much larger (kVAR) than the capacitor at the low-voltage bus. Generally, this situation occurs most frequently for substation switching. The frequency of oscillation that occurs when the high-voltage capacitor is energized is close to the resonant frequency formed by the stepdown transformer in series with the low-voltage capacitor. There is little resistive load on the low-voltage system to provide dampening of the transient, as is usually the case for industrial plants (motors do not provide significant damping of these transients). It is not uncommon for magnified transients at low-voltage capacitors to range from 3.0 to 4.0 per unit. These transients have significant energy associated with them and are likely to cause failure of protective devices, metal oxide varistors (MOVs), electronic components (silicon-controlled rectifiers, etc.), and capacitors. VSDs are particularly susceptible to these transients because of the relatively low peak-inverse voltage ratings of the semiconductor switches and the low-energy ratings of the MOVs used to protect the VSD power electronics. The following should be evaluated and identified in the specifications to control these magnified transient overvoltages: using vacuum switches with synchronous closing controls to energize the capacitor bank and control the capacitor-switching transient; providing high-energy MOV protection on the 480 V buses (the energy capability of these arresters should be at least 1 kJ); using tuned filters for power factor correction instead of just shunt capacitor banks (the tuned filters change the frequency response of the circuit and usually prevent magnification problems. This solution combines power factor correction, harmonic control, and transient control).

D.15.4 Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) Concerns

IEEE Standard 519, Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, recommends limits for voltage distortion and harmonic current resulting from nonlinear loads. However, the IEEE standard is not intended to cover the effects of RFI. As a result, specifications will occasionally refer to Federal Communications Commission (FCC) Rules and Regulations, Volume 2, Part 15, Subpart J, Class A (referred to as "FCC rule") to establish limits on electromagnetic emission for VSDs. The FCC rule was printed in October 1982 primarily for computing devices. Computers will generate RF energy and possibly cause interference with nearby equipment if misapplied. Generally, the rule sets conducted and radiation RF limits for electronic devices using timing signals or digital techniques with pulse rates in excess of 10,000 pulses per second. Technically speaking, VSDs with high-frequency timing circuits conform to this description, although they are not intended as a computing device described in the FCC rule. The primary and more significant source of EMI from a VSD stems from the power circuits, and in this respect, drives become an incidental radiation device. The only requirement for incidental radiation devices in the FCC rule is that they shall be operated so the RF energy emitted does not cause harmful interference -- if so, the operator must eliminate the interference. All VSDs, regardless of the manufacturer, will produce electromagnetic emission to some degree. Primarily, these emissions are due to the steep wave-fronts and very rapid switching of power semiconductors in the VSD. Typically this occurs when transistors, GTOs, or other "fast devices" are gated on and off in DC chopper circuits and invertor power circuits for PWM, current source, and six-step drives. Typically conductors to the VSDs and motor act as an antenna and radiate the RF energy into the media. Therefore it is possible for RF to be induced into nearby antennas and other conductors, and be carried to the loads in that circuit. Holding a portable AM radio near a power outlet in close proximity to an EMI source can be evidence of this situation. Distributive digital control (DDC) systems, telecommunication services, and other electronic equipment utilizing very high frequencies may experience noisy interference or malfunctions when subject to EM/RF energy. The specification should clearly outline the corrective measures required. The first and foremost corrective measure to avoid problems associated with EMI is proper routing of the drive conductors in separate metallic conduits, and even separate raceways if practical, and as remote as possible from any other conductors or suspect equipment. Usually, this will be sufficient to avoid EMI problems. EM/RF filters can be engineered for a system to trap or inhibit high-frequency emissions into power system conductors. However, due to the nature of EMI, the effectiveness of any filter is highly sensitive to where it is installed. Further, it is not assured that the filter will correct the problem even though it may meet FCC limits. Most manufacturers will include this footnote with their literature: "Filters are expensive and usually require additional space. It is recommended that they be furnished only when they are specifically required to avoid or solve a problem after exhausting all proper installation methods.

In addition, filters are an additional component and must be considered in the overall reliability of a power system.” To contain RF radiation through the media from the VSD, complete shielding using a metallic enclosure is required. This will usually contain most of the radiated RF to a reasonable distance.

D.16 HVAC Systems

D.16.1 Types of Systems

The HVAC systems at the NIH Buildings are highly diverse and must satisfy a large variety of program requirements. The challenge to the HVAC designer is to accurately define system operating parameters, and to control strategies, heat load data, utility requirements, and program equipment needs. The design engineer must take a proactive role in the early design stages so that operating requirements defined clearly and concisely. HVAC systems must fully support the program of requirements, utilize state-of-the-art, efficient technology, and promote the health and safety of building occupants.

Proposed system alternatives must be evaluated fairly with consideration given to operating and maintenance cost, reliability, flexibility, redundancy, and the value of lost research in the event of system failures. The health and safety of building occupants drive the need for good indoor air quality, and all system alternatives must fully comply with the requirements of these guidelines.

D.16.2 All-Air Systems

In air systems the air supplied to the spaces provides the cooling and heating capacity necessary to produce the desired temperature, dehumidification, filtration, ventilation, and humidity levels for comfort or process control. The fan energy required for the distribution of the air can be quite significant and is dependent upon the quantity of the air, pressure drops in the conditioning equipment and ductwork, fan and drive efficiencies, and hours of operation. Although ventilation for reduction of contaminants may govern frequently in labs, animal spaces, and special spaces, the quantity of air is usually determined by and is proportional to the space-sensible cooling or heating load and inversely proportional to the difference between room and supply air temperatures. Consequently, reduction in the space-cooling load through prudent design of the building envelope and lighting will produce a reduction in air volume and hence a reduction of the required energy consumption.

Fan energy consumption shall be optimized through the design of the conditioning equipment, selection of components, and duct design.

Air-handling equipment including intake and exhaust louvers, filters, and heating and cooling coils can be optimized by selection at a conservative face velocity. Lower face velocities can be justified by life cycle cost analysis. Filter life may be improved by reducing face velocity, permitting an economically justifiable lower final pressure drop (before replacement).

Simpler, shorter duct systems designed with conservatively low duct velocities are consistent with energy efficiency objectives and offer acoustical benefits. High-loss fittings, such as mitered elbows, abrupt transitions, and takeoffs and internal obstructions shall be avoided. Long duct runs, if necessary, should be designed with special consideration of pressure loss since the maximum loss for any run shall be imposed upon the entire fan system. Duct systems should be designed at the lowest pressure possible given the physical restrictions within buildings.

Air systems shall serve spaces having similar operating characteristics. Spaces with different periods of occupancy or substantially different ventilation requirements shall not be combined on the same system. Dedicating air systems to specific departments provides proper grouping of spaces with similar occupancy characteristics and environmental performance requirements and simplifies the duct distribution systems.

The usage of cold air distribution may be considered for an energy conservation method. However, there are several factors that the A/E must address to assure that the system successfully distributes the cold air. Cold air distribution systems supply air for space comfort conditioning at nominal temperatures between 3 and 11^{0}C, as opposed to conventional supply temperatures of 13 and 15 ^{0}C. This approach has been applied primarily to take full advantage of the 1 to 3 ^{0}C chilled water available with ice storage.

The A/E should assess the full economic impact of the system, such as first-cost reductions which come from the decreased size of air handlers, fans, ducts, chilled water pumps and piping. In new buildings, there will be structural cost savings due to the decreased floor-to-floor height requirements of smaller ducts. First costs may increase for cooling coils, terminal units, duct insulation, and the cooling storage system, but the net effect may be a reduction in total system costs. Typically air and water distribution cost reduction of 15% to 20% depending on the size of the system can be achieved by lowering the supply air temperature from 13^{0}C to 7^{0}C. The net cost reduction, including refrigeration and storage equipment costs, which are typically 6% to 11% when comparing a conventional chiller system with 13^{0}C supply air and an ice storage system with 7^{0}C supply air.

Systems using nominal 7^{0}C supply air (range of 6^0 to 8^{0}C) should be emphasized, because they offer the greater benefits for application with ice storage. The nominal 3^{0}C supply air (5^{0}C below) should not be recommended due to the requirement of more specialized equipment and design effort, with little additional savings.

Very often overlooked parameters in the economic impact are:

- The cooling energy, which increases with cold air distribution because more dehumidification is performed than is required for room comfort, and

- The penalty for the reduced availability of economizer cooling

The consultant shall consider that at the typical relative humidity (RH) levels of 35% to 45%, dry-bulb temperature can be increased -17^{0}C to -16^{0}C above conventional room comfort setpoints, and occupants will perceive the same comfort conditions. This effect can result in a 5% to 10% reduction in cooling energy, and in most cases is critical to achieving a net energy reduction with cold air distribution. The optimum supply air temperature should be determined by an economic analysis that considers changes in first costs and operating costs for various design options.

A blow-through configuration, with the cooling coil downstream of the supply fan, should be utilized for the cold air distribution systems. This allows the fan heat to be absorbed directly in the coil, resulting in a supply air temperature -17^{0}C to -16^{0}C lower than for a draw-through configuration. Coils with 8 to 12 rows should be used to provide supply air at 6^{0}C to 8^{0}C. Fin spacing should not exceed 12 fins per square meter, and the fin configuration should allow easy cleaning.

A high chilled-water temperature rise in the coil is recommended to reduce pumping horsepower and to increase the efficiency of refrigeration equipment operating in chiller mode. In general, a -7^0C rise can easily be achieved with storage system. A -4^0C rise is recommended for cold air distribution systems, and in some cases a rise as high as -1^0C.

The coil face velocity should not be more than 350-450 fpm, with a maximum limit of 450 fpm. A low face velocity requires a large coil and air-handling unit but achieves better coil heat transfer and a lower supply air temperature. A higher face velocity results in smaller equipment but is limited by carryover of moisture from the coil into downstream ductwork.

The A/E shall be aware of oversizing of coils with ice storage systems which can lead to problems and should be approached with care. Excessive dehumidification and poor control of chilled water flow can result, along with overcooling of the space, if the air side is also oversized.

Round ducts should be used for the cold air distribution. If round ducts cannot be used, the aspect ratio (ratio of width to height) of rectangular ducts should be minimized to reduce pressure losses and initial costs.

The minimum insulation thickness for a cold air distribution system will be determined by requirements for preventing condensation. The optimum thickness, which will likely be greater than this minimum, is determined by an economic analysis of the cost of additional insulation versus the penalties from duct heat gained and increased supply-air temperature. These penalties include the increased size of equipment and additional energy consumption.

A direct cold air supply requires the use of diffusers that will perform satisfactorily with the expected supply air temperatures, especially at low loads. The design must be such that colder, low-velocity air will not dump directly into the space. Before designing such a system, the diffuser manufacturer must be consulted and tests run to ensure that the diffuser will perform adequately with the expected supply air temperature. Long supply-air ducts run can have a temperature rise of -15^{0}C to -13^{0}C at low airflow. In such cases, the duct temperature rise at low loads may prevent dumping for systems with supply air as low as 6^{0}C at the cooling coil.

D.16.3 Air and Water Systems

Air and water systems shall be composed of a central ventilation system and four pipe-fan coil units. The system shall utilize both chilled water and hot water piping to each terminal fan coil unit.

Controls for room fan coil units shall be sequenced to avoid simultaneous heating and cooling with provisions for an adjustable dead band between cooling and heating modes, unless relative humidity control is essential, in which case simultaneous cooling and heating may be considered.

Fan coil units may be utilized to provide supplemental cooling for equipment areas or other spaces with large internal heat gains and limited ventilation requirements.

The central air systems will be utilized in conjunction with the fan coil units to maintain minimum ventilation rates. Induction-type terminal units shall not be utilized.

Secondary pumps designed for the heating or cooling piping loops shall be automatically controlled to shut off when their function is unnecessary.

Shut off gate valves shall be used in all heating, glycol, water, industrial hydronic systems, steam and condensate lines. (Recommended use of OSAY 300# ANSI for high pressure and 150# ANSI for medium and low pressure system). Bronze stemmed Gate Valves manufactured by Grinnel, Vale and Jerkins are recommended for use at NIH campus.

High performance butterfly valves may be used for chilled water, domestic or industrial cold water services. Gate valves arepreferred and the use of butterfly valves for different applications shall be evaluated by the Project Engineer in consultation withMaintenance Engineering Branch.

Full ported top entry or three piece bronze, stainless steel ball valves may be used on all water and gas services for sizes 50mm or less.

D.16.4 Unitary Equipment

The use of unitary equipment shall be restricted to serve unique areas, such as computer rooms and support facilities, or as required to maintain specific environmental conditions.

D.16.5 Sound Lining

Duct lining is not permitted for use in duct systems. Omission of duct lining usually requires sound attenuators in order to meet the specified NC criteria. A sound analysis shall be performed to ascertain the need of terminal sound attenuators.

Sound attenuators shall be selected for low velocities and low pressure losses. High-velocity selection shall be avoided due to the pressure loss and internally generated noise. Sound attenuators shall have approved lining material to prevent insulation fibers from becoming airborne.

D.16.6 Plenums

The use of plenums or air shafts for air distribution (supply, return, or exhaust) is prohibited in NIH buildings. Common outside duct may be permitted for multiple air intakes to Air Handling units due to the constraints on space and building configuration. Corridors, exit passageways, stairways, and other similar spaces shall not be used as plenums or transfer air paths as defined by NFPA and the BOCA International Building Code.

D.16.7 Indoor Air Quality

Providing acceptable indoor air quality (IAQ) in NIH buildings is the responsibility of the A/E. The guidelines define acceptable IAQ levels and recommend methodologies to achieve those levels. Typical contaminant control measures include dilution ventilation, local exhaust ventilation, and air cleaning.

The use of mechanical ventilation to maintain relatively comfortable and odor-free indoor spaces is based on the principles of general dilution theory. By doubling the volume of air available for dilution under static or constant conditions of contaminant generation, a 50% reduction in contaminant concentration can be expected. If the air volume is doubled again, the concentration will be reduced to 25% of its original value, and so on. The converse is also true. By reducing the air volume available for dilution, contaminant concentrations would be expected to correspondingly increase.

However, dilution ventilation is not as effective in many cases. In those instances where contaminants such as formaldehyde and volatile organic compounds (VOCs) are released from sources by diffusion, emission will vary in response to changes in environmental conditions such as temperature, relative humidity, and ventilation rates themselves. Increased ventilation rates, for example, produce vapor pressure exchanges around sources, which cause emission rates to increase. This phenomenon has been reported for formaldehyde and a number of VOCs. With VOCs, a sixfold increase in the ventilation rate will result in a twofold increase in source strength.

The shortcomings of dilution ventilation should be fully addressed by the A/E. There are a lot of schools of thought regarding the calculation of the removal of contaminants in a closed space. The A/E shall use the following approach to assess the contaminant of purge and dilution removal rate. It is the basis and fundamental relationships available for determining the various parameters associated with the reducing the concentration of the vapor of any volatile material in a closed space or room.

$$C = C_o e - [V_{removed} 1 V_{room}]$$

Where:

C = the ending concentration of the vapor in the closed space or room, which ending concentration, measured in ppm, resulted from the purging activities;

C_o = the initial concentration of the vapor in the closed space or room that is to be reduced by purging, also measured in parts per million;

$V_{removed}$ = the air volume that has been withdrawn from the closed space or room, measured in any suitable volumetric units, usually in cubic feet; and

V_{room} = the volume of the room, measured in the same volumetric units as $V_{removed}$ which is usually in cubic feet.

An example of the use of the above equation would be if the A/E needs to assess the "room volumes" of air that must be withdrawn (purged) from a room in order to reduce the concentration of any volatile substance in the ambient air of that room by 90% or by 99%. From the perspective of the applicable formula listed above, this asks for a value of n, where n is the number of room volumes for which--once this volume of ambient, volatile-filled air had been removed from the space--would result in a situation where the residual room concentration of that volatile would be at or below the identified target concentration level. Specifically, they seek an exponent of e in the following general format:

$$\frac{n\ V\ room}{V\ room}$$

Clearly the $\underline{\text{V room}}$ terms will cancel out, leaving the simple exponent value of n. The formula therefore evolves to the following:

-n $\underline{\text{ V room }}$

$$C = C_o e^{\frac{-n\ V\ room}{V\ room}} = C_o e^{-n}$$

The task for the A/E is simply to determine the value of n, as a number of room volume, that corresponds to:

- a decrease in the ambient concentration to a level that is only 10% of the starting value (i.e., the ending concentration, $C_{90\%}$, has the value 0.1 C_o, and

- a decrease in the ambient concentration to a level that is only 1% of the starting value (i.e., the ending concentration, $C_{99\%}$“, has a value, $0.01C_o$).

$$C_{99\%} = 0.1\ C_o = C_o e^{-n99\%}$$

$$0.1 = e^{-n90\%}$$

$$\text{In } 0.1 = -n_{99\%} = -2.303$$

$$n^{90\%} = 2.303$$

For a 99% reduction in the concentration:

$$\text{In } 0.01 = n_{99\%} = -4.605$$
$$n_{99\%} = 4.605$$

To achieve specified reductions in the ambient concentration of <u>any</u> volatile substance, one must purge the following number of *room volumes* to attain the identified target reduction in the ambient room concentration level:

Target Reduction (%)	# of Room Volumes
90%	-2.3
99%	-4.6

It appears that ventilation rate increases from 2.5 to 10.0 L/s per person are associated with decreased sick-building syndrome (SBS) symptom prevalence rates, while under other conditions it may provide no benefit. As such, ventilation cannot and should not be viewed as a generic solution to IAQ problems. The limited effectiveness of general dilution ventilation in reducing the prevalence of SBS symptoms may in part be due to the nature of toxic exposures that cause irritation systems. In the studies of Alarie and Anderson, irritant effects of formaldehyde and other VOCs in mice have been demonstrated to be log linear. What this means in a practical sense is that a 90% reduction in exposure concentration is required to reduce irritant response by 50%. The log-linear does-response relationship for irritant chemicals indicates that order-of-magnitude increases in outdoor air exchange rates would be required to have a significant reduction in irritant symptom response. Achievement of such air exchange conditions in most buildings is impractical if not impossible.

Studies designed to evaluate the effect of increased outdoor ventilation rates have also reported mixed results. In a study of a five-story office building, Palonen and Sepanen observed no apparent relationship between ventilation rates and measured indoor concentrations of carbon dioxide (CO_2), formaldehyde, VOCs, particles, bacteria, mold, and random. In the studies of Nagda, there were no significant effects of outdoor ventilation rates on concentrations of formaldehyde, nicotine, and total VOCs with marginally significant increases of CO_2, formaldehyde, respirable particles, nicotine, and microbial concentrations were observed under nominally high ventilation rates in reducing contaminant concentrations in the studies of Nagda and Collett were in good measure due to their inability to control actual air exchange conditions because of the confounding effect of infiltration.

The reduction of contaminants generated by building occupants has historically been the primary reason for ventilating buildings. These contaminants, described as human bioeffluents, produce unpleasant odors which are perceived by individuals entering a building spaces. They are also believed to be responsible for sensory perceptions of "stuffiness," "stale air," and discomfort associated with poorly ventilated buildings. The studies of Fanger have confirmed a portion of the dissatisfaction reported. Contaminants emitted by humans into building spaces have received only limited chemical characterization. As a consequence, bioeffluent levels are described in terms of CO_2, the bioeffluent produced in the greatest concentration and the most easily measured. CO_2 levels are used as a measure of the acceptability of indoor air relative to ventilation adequacy. The relationship between CO_2 generation rates, occupant density, and outdoor ventilation rates has been well established and serves as the basis for the ASHRAE Standards and WHO guidelines for acceptable IAQ. Because bioeffluent levels determined from CO_2 measurements have a relatively constant generation rate for a given occupant density, increased actual outdoor ventilation rates have a predictable effect on bioeffluent levels in buildings. Effects of high and low outdoor ventilation rates as well as occupant density on CO_2.

A consensus has formed over the years that adequate ventilation is essential for the maintenance of a comfortable and relatively human-odor-free building environment. As a consequence, standards and guidelines have been developed to assist both designers and building operators in providing adequate outdoor ventilation air to meet the needs of building occupants. The lead professional organization for developing and recommending ventilation standards and guidelines for acceptable IAQ in North America has been the ASHRAE. In Europe, such guidelines have been typically developed under the auspices of government agencies, regional collaboration, and the WHO. Different approaches have been used or suggested for developing ventilation standards/guidelines for the purpose of addressing odor, comfort, and health concerns. These are described as ventilation rate (VR), IAQ, and perceived air quality (PAQ) procedures.

The VR procedure has a long history of use. It specifies a rate of outdoor ventilation that can be reasonably expected to provide acceptable air quality related to humans themselves. Ventilation guidelines reflect the percentage of outdoor air that will maintain a steady-state CO_2 concentration in the building that does not exceed a maximum acceptable value. They are usually specified in terms of L/s per person. Under the design occupancy, the provision of the specified minimum ventilation rate would be expected to maintain CO_2 levels below guideline values. As such, the VR procedure prescribes the minimum amount of outdoor ventilation air required to meet air quality goals. The minimum outdoor ventilation rate for office buildings in both ASHRAE Standard 62-73 and Standard 62-1981 was 2.4 L/s per person. At maximum design building occupancy, this ventilation rate would cause CO_2 levels to rise to 2,500 PM. This ventilation guideline reflected a significant concern for energy conservation and a reduction in the importance of human comfort and health. The explosion in SBS complaints in the late 1970s and throughout the 1980s and attempts to mitigate them by general ventilation led many in the IAQ community to conclude that prescribed ventilation rates were too low and were in fact a major contributing factor to the SBS "epidemic." As a consequence, ASHRAE guidelines were revised to provide a minimum ventilation rate of 10 L/s per person in the typical mechanically ventilated office space, with other ventilation rates for more specialized circumstances, such as smoking lounges, 30 L/s per person. In the former case, the CO_2 concentration would not be expected to exceed 800 ppm. This is similar to the WHO guideline. The ASHRAE IAQ guideline for CO_2 is, however, 1,000 ppm. Though originally developed to address IAQ and comfort concerns associated with human bioeffluents, guidelines based on the VR procedure have unfortunately become the generic measure of IAQ acceptability irrespective of what the contaminants and contaminant sources are. Indeed, the document developed for ASHRAE Standard 62-1989 states that prescribed ventilation rates will result in acceptable levels of CO_2, odors, and other contaminants. No evidence, however, was presented to show that there was any relationship between indoor CO_2 levels and other contaminants or between CO_2 levels and SBS complaints. ASHRAE guidelines as a measure of IAQ acceptability other than for human bioeffluents have no scientific basis. Their use as a measure of acceptability of air quality in many building investigations has therefore been inappropriate. The scientific shortcomings of ASHRAE Standard 62-1898 based on the VR procedure have ben addressed by Grimsrud and Teichman. Grimsrud, a member of the ASHRAE committee which developed the censure ventilation guidelines by means of the VR procedure, suggests that ASHRAE Standard 62-

1989 should be seen as a transition document to be updated when new scientific data on health effects and emission rates of indoor contaminants become available.

With all the facts and background mentioned above, the A/E assessing VR should be fully familiar with the current standards and their background. As a part of IAQ and VR analysis the Architect/Engineer shall evaluate the continuous, multipoint sampling of CD_2 concentrations (known as demand-controlled ventilation) for the following reasons.

- The A/E will be able to base effective ventilation rates on actual occupancy patterns and can save energy in installations where there are significant variation in occupancy patterns.
- This could be an improvement over an approach in which outdoor air damper settings are a best guess and would be avoid situations which risk overventilating and have degraded CO_2 during maximal occupancy.
- This procedure is appropriate only when people are the primary source of air contaminants.
- It is especially useful in buildings with highly variable and unpredictable occupancy patterns, such as auditoriums, and some offices.

The A/E will then be able to identify and respond to combustion air contaminants impacting outdoor air intakes:

- Motor vehicles have CO_2 concentrations of 150,000 ppm at the tailpipe.
- Outdoor air contaminated with 1% vehicle exhaust would yield 1,850 ppm.
- A system could be set up to close outdoor air dampers when outdoor air exceeded 2,000 ppm of CO_2, thus preventing fumes from entering the building.
- When outdoor CO_2 returned to background levels, dampers would reopen.

Proactive system diagnostics will permit the ability to:

- Assess the relationship between supply air distribution and distribution of people throughout the building due to nonuniform peaks of CO_2 values.

- Identify inadequacies in the duration of the ventilation, because morning CO_2 will not have decreased to outdoor values.

- Identify leakage of outdoor air or supply air into the return plenum when return air CO_2 values do not correspond to occupied space values.

- Identify periodic reentrainment of building exhaust.

- Both identify problems and assess the magnitude of benefits achieved by mitigation and corrective efforts.

- Document the adequacy of effective ventilation rates during varying occupancy and outdoor conditions.

D.16.8 Air-Handling Systems for Laboratory Buildings

Laboratory buildings shall be designed with “once through,” 100% outdoor air systems that automatically compensate for filter loading. Laboratory air will not be recirculated. Systems shall have pressure-independent hot water terminal reheat devices and individual laboratory module and/or office area temperature zone control. The HVAC system shall be designed to maintain the proper temperature, humidity, differential pressure, outdoor air exchange rate, and acoustic criteria within the space. Laboratory building air systems shall operate continuously year round. The HVAC system capacity shall be based on the largest of the two main parameters specified below:

- The amount of fume hood exhaust required to meet actual design requirements or the minimum exhaust requirement set by chemical fume hood density policy at the NIH, whichever is greatest. If the required exhaust to meet actual fume hood demand is less than the air exhaust required to meet minimum hood density requirements of one nominal 1.2 m wide vertical fume hood (354 L/s) for every other laboratory module, then the fume hood exhaust demand shall be based on NIH Fume

Hood Density Policy.

- The required space cooling loads. This is primarily a function of thermal transmission, solar loads, associated laboratory support equipment, and lighting loads. At the NIH, a combined laboratory equipment and lighting load density of 11 W/nsm shall be used as a minimum in design of laboratory areas (86 W/nm^2 for equipment, 32 W/nsm for lighting).

The ventilation rate shall also be sufficient for the removal of contaminate. The following equation provides a single relationship that makes it possible to calculate the steady-state, equilibrium concentration that would be produced in a room (or any enclosed space for which the overall volume can be determined) by the <u>complete evaporation</u> of some specific volume of <u>any</u> identifiable volatile solvent.

$$C= \left| \frac{V_s p\ T}{[MW_s]\ P_{atm}\ V_{room}} \right| [6.24 \times 10^7]$$

Where:

C= the equilibrium concentration of the volatile solvent that would be produced in the room by the evaporation of the known volume of solvent, <u>C</u> measured in ppm;

V_s = the volume of the solvent that has evaporated, measured in milliliters;

= the density of the solvent, measured in grams per cubic centimeter;

T = the temperature in the room, measured in degrees Kelvin;

Mw^s = the molecular weight of the solvent;

P_{atm} = the ambient barometric pressure that is prevailing in the room, measured in millimeters of mercury;

V_{room} = the volume of the room, measured in liters; and 6.24×10^7 the proportionality constant that makes this equation valid, under NTP conditions.

The following equation is know as the basic room purge equation. It provides the necessary relationship for determining the time required to reduce a known initial high-level concentration of any vapor -- existing in a defined closed space or room -- to a more acceptable ending lower-level concentration.

$$D_t = \frac{|V|}{|Q|} \quad \text{IN} \quad \frac{|C_{initial}|}{|C_{ending}|}$$

Where:

D_t = the time required to reduce the vapor concentration in the closed space or room, as required, measured in minutes;

V= the volume of the closed space or room, measured in cubic meters;

Q= the ventilation rate at which the closed space or room will be purged by whatever air-handling system is available for that purpose, measured in cubic meters per second;

$C_{initial}$ =the initial high-level concentration of the vapor in the ambient air of the closed space or room, which concentration is to be reduced -- by purging at q m^3/m -- to a more acceptable ending lower-level concentration, measured in parts per million; and

C_{ending} =the desired ending lower-level concentration of the vapor that is to result from the purging effort in the closed space or room, also measured in parts per million.

The application of the above equations can provide required liters per second for dilution and assess fume hood stack concentrations that cannot be used to calculate the reentrainment of contaminated air into outdoor air intake which is referred to in the guidelines. The guidelines identify the use of ASHRAE methodology to locate intakes and stack outlets. However, ASHRAE does not have any guidelines on the required dilution rates. Therefore the methodology identified in by ASHRAE cannot be used without a set dilution requirement.

It is recommended that the reentry be assessed on the basis of the spill of a volatile compound. The spill area will be the fume hood pan (0.813 m^2 with Reynolds number of 30,000). From this information the diffusivity in the air, mass transfer, and stack coefficient can be evaluated and then, by using ASHRAE methodology with a 1000-rate dilution, the reentry concentrations can be calculated.

The use of the above equations can be used in situations such as the following: a 1.50 L glass bottle full of acetone (MW = 58.08, density = 0.891 g/cc and vapor pressure = 226 mmHg at 25^0C) is spilled from its position on a shelf, breaking when it hits the floor of a lab that has a volume of 47 m^3 cubic feet. If all the acetone evaporates, what will the ultimate ambient concentration of acetone be in the room? Is it reasonable to assume that all the <u>acetone</u> will evaporate? To solve the final part, both Dalton's Law of Partial Pressures and Raoult's Law will have to be applied to the solution obtained in the first part. To solve the first part, the above equations are used:

$$C = \left| \frac{V_s P}{[MW_s]\, P_{atm}\, V_{room}} \right| [6.24 \times 10^7]$$

$$C = \left| \frac{(1.5)\,(1{,}000)\,(0.79)\,(273.16 + 25)}{(58.08)\,(760)\,(1{,}650)\,(28.32)} \right| [6.24 \times 10^7] = 10{,}702 \text{ ppm}$$

The ultimate ambient concentration level of the acetone vapors in this room will be - 10,702 ppm. According to Raoult's Law, the partial vapor pressure of any volatile component will be the product of the vapor pressure of the pure component and the Mole Fraction of that component in the solution being considered. This case, deals with pure acetone; thus, the mole fraction will be 1.00 = 100% and Raoult's Law shows that the “potential” for the partial vapor pressure of acetone would simply be its pure state vapor pressure, or 226 mmHg. Applying Dalton's Law of partial pressure to this fact:

$$C_{max} = \frac{[1{,}000{,}000]\ [PVP_{acetone}]}{P_{ambient}}$$

$$C_{max} = \frac{[1{,}000{,}000]\ [226]}{760} \qquad =8.772$$

It is reasonable to assume that all the Acetone will evaporate, since the Concentration that would be produced by the Quantity of acetone in that was broken during the fall is only a small fraction of the Theoretical Maximum Acetone Concentration that could exist in the Ambient Air (10,702 ppm vs 297,368 ppm, with the former being only 3.6% of the latter). In fact, in a room for the size given, 41.7 liters of pure Acetone could reasonably be expected to evaporate completely. From this one calculates the fume hood stack concentration and required liters per second for purge. For example if the goal is to ventilate the room until the acetone concentration is at or below the TLV-TWA concentration, which for acetone is 750 ppm, and if the room's ventilation system has a flow volume capacity of 236 L/s, it will take 8.7 minutes to reduce the acetone concentration to the required level. Because:

$$D_t = \frac{|\ V\ |}{|\ Q\ |} \quad \text{IN} \quad \frac{|\ C_{initial}\ |}{|\ C_{ending}\ |}$$

$$D_t = \frac{1{,}650}{500} \quad \text{IN} \quad \frac{10{,}702}{750} = 8.772$$

The question frequently asked is what chemical to use in the ventilation and reentry calculations. The answer is chemicals with highest vapor pressure and highest ACGIH-STEL and order threshold limits. The few specific chemicals used for such calculation in industry are acetone, acetaldehyde, chlorobromomethane, cyclohexane, etc.

HVAC system design for equipment support areas, glasswash areas, sterilizer facilities, conference rooms, offices, etc. shall be based on actual loads and conditions. The A/E shall thoroughly review the program of requirements to understand the scope and magnitude of miscellaneous space.

Laboratory buildings shall be supplied with multiple, manifolded air-handling units (AHUs) such that upon failure of any major component related to an AHU, the remaining available HVAC air-handling equipment will provide 100% capacity. A parallel system design using two or more pieces of air-handling equipment which operate simultaneously to meet full load conditions is the preferred choice to ensure overall system air-handling reliability. Each AHU and its related components shall be capable of being totally isolated from the remaining operational units to accommodate routine maintenance and emergency repairs in the advent of equipment failure.

The laboratory exhaust systems, where there is no mixture incompatibility, shall be arranged with multiple manifolded fans designed to maintain 100% of exhaust design conditions at all times. The number of fans shall be determined by the A/E to accommodate physical and capacity restraints. One of the fans shall be provided as a backup for any other single fan. Upon the loss of flow through any one fan, the designated backup fan shall be energized to maintain a constant exhaust system flow. The fan designated as a backup shall be automatically alternated among all system exhaust fans so that all motors and equipment experience approximately the same running time. Exhaust fan motors and drives must located out of the airstream. Each fan shall be fully isolated from the others to accommodate routine service while the overall system is operational.

Exhaust air from laboratory equipment such as fume hoods and biosafety cabinets directed to a general central laboratory exhaust main is preferably controlled through pressure-independent terminal units.

Supply fans shall be energized after exhaust fans are operational and exhaust flow is confirmed.

No positive pressurized segment of any laboratory exhaust system shall be located in any occupied zones. Offices within the mechanical rooms are classified as occupied zones. The design shall permit the installation of exhaust fans at the end of exhaust lines and as close as possible to the final point of discharge to avoid or minimize leakage to the space, particularly mechanical areas. The positive pressure segment of exhaust system shall be constructed per the SMACNA standard for 1,494 Pa water-gauge positive pressure. A leak test shall be performed to verify the SMACNA allowable leakage rate as defined in the *High Pressure Duct Standard*, Third Edition, Chapter 10.

All toilet and general-use exhaust shall discharge through a separate exhaust system.

In buildings housing both laboratories and other types of space with distinct occupancy zones in which the lab areas are segregated from other types of space, a separate HVAC system for the laboratory area is mandated.

The HVAC designer is required to get approval from the NIH Division of Safety regarding exhaust mixture compatibility to avoid cross contamination upon system failure or equipment damage due to an incompatible mixture.

Exhaust from central sterilizers, cage-wash equipment, and glasswash areas shall have a separate exhaust system. Wet exhaust ductwork shall be pitched for drainage back to hood. Moisture eliminators should be considered for use at hoods.

As a minimum, supply air for these areas shall pass through a prefilter and filter on the upstream side with efficiencies of 30% and 95% respectively, based on ASHRAE Standard 52-76, atmospheric dust-spot test efficiency. Special areas may require greater filtration on both the supply and the exhaust sides. The requirements for additional exhaust filtration shall be coordinated with the NIH Division of Safety, Occupational Safety and Health Branch and Radiation Safety Branch, where specific hazardous program functions occur.

Ventilation of environmental rooms shall be addressed on design documents. Those rooms that serve as occupied functioning lab spaces shall receive outdoor air ventilation at the rates defined by

ASHRAE Standard 62-1989. Environmental rooms used primarily for storage functions do not require ducted ventilation air.

Air systems will require humidification to meet space humidity requirements. Low-pressure, dry-steam, direct injection humidification to introduce clean steam supplied by vaporizing softened water in a steam-to-steam generator shall be used for humidification. Duct humidifiers should be located downstream of fans. Ductwork within the absorption range of the humidifier shall be stainless steel with a drainage facility.

Each individual room shall be balanced for the actual airflow requirements (The highest cooling load or make-up air/ventilation airflow requirement). The central supply and exhaust air system shall be balanced for the total of individual airflow requirements in each room plus the allowable duct leak based upon the SMACNA duct construction manual. A diversity factor shall be applied if a variable air volume system is used. The central supply and exhaust air system shall be sized based on the following procedures:

- List the individual room total air requirements accounting for hoods, sensible heat loads, and minimum air change rates.
- Eliminate from the list those laboratory modules that currently have fume hoods.
- Calculate the additional airflow that would be required if 1.2 m, vertical sash fume hoods were added to half the remaining laboratory modules. Assume that the hoods are added to the rooms with the lowest airflows.
- Add the allowable total system duct leakage to the total from the previous item, to determine future expansion requirements.
- Size all AHU system components and duct mains to allow for future expansion.
- Include in the system design not only the required airflow for present conditions but also the future expansion. In the design calculation, describe the modifications that would be

required to achieve the future expansion requirements and the reasoning behind the system sizing including the life cycle cost considerations.

- As a minimum, select main supply and exhaust fan motors one size larger than the required motor watts, and size the fan a minimum of 20% greater than the required present airflow L/s.

- Size individual exhaust and supply branches for the greater of the present airflow requirement or a 250 mm equivalent duct diameter.

D.16.9 Air-Handling Systems for Vivarium Buildings

The air-handling system design shall comply with the requirements described in the *Guide for the Care and Use of Laboratory Animals*, current edition. The animal facility's HVAC system design shall be based on 100% outdoor air and shall automatically compensate for pressure variations due to filter loading. Vivarium air will not be recirculated. The system shall be outfitted with pressure-independent hot water terminal reheating devices, and humidifiers and provide individual space temperatures and humidity control. Individual control must be provided for each holding room, treatment room, procedures room, and operating room. The HVAC system shall be designed to individually control and maintain the proper temperature, humidity, differential pressure, and outdoor air exchange rate at all times within the facility. The HVAC system capacity shall be based on the largest of the four main parameters specified below:

- Minimum ventilation requirements of outdoor air changes per hour throughout animal use area shall be based in accordance with chapter 21 of ASHRAE Application Handbook-1999 and NIH publication "Ventilation Design Handbook on Animal Research Facilities using Statc Microisolators Vol I and Vol II".

- The amount of fume hood and downdraft table exhaust required to meet actual program requirements if there are animal research laboratories and procedure rooms within the facility

- The required space-cooling loads to meet environmental conditions specific to the type of animal. This is primarily a function of thermal transmission, solar loads, associated laboratory support equipment, and animal and lighting loads

- Minimum ventilation requirements as required to support micro environments in ventilated cage racks

If microenvironments are employed for animal holding, the minimum ventilation requirement may be reduced to10 outdoor air changes per hour plus the sum of the microenvironment airflow. System connections to microenvironments shall be designed to maintain the manufacturer specified criteria.

HVAC systems serving animal facilities shall be designed with parallel heating, ventilating, and air-conditioning system arrangements or standby equipment with capability to ensure continuous operation during equipment failure and scheduled maintenance outages. Parallel operation using two or more pieces of equipment which operate alternately to meet full load is the preferred choice. Whenever parallel equipment is not possible, redundancy is required by means of standby equipment which handles the full load and operates when the primary system fails. Each AHU and its related components shall be capable of being totally isolated from the remaining operational units to accommodate routine maintenance and emergency repairs in the advent of equipment failure.

The exhaust system shall be designed for and utilize a multiple-fan exhaust arrangement. The number of fans shall be determined by the A/E to accommodate physical and capacity restraints. One of the fans shall be provided as a backup for any other single fan. Upon the loss of flow through any one fan, the designated backup fan shall be energized to maintain a constant exhaust system flow. The fan designated as a backup shall be automatically alternated among all system exhaust fans, so that all motors and equipment experience approximately the same running time. Exhaust fan motors and drive must be located out of the airstream. Each fan shall be fully isolated from the others to accommodate routine service while the overall system is operational.

In buildings housing both laboratories and other types of space with distinct occupancy zones in which the animal areas are segregated from other types of space, a separate HVAC system for the animal areas is mandated. Both areas may use common standby unit if the situation permits to save the cost.

All toilet and general-use exhaust shall discharge through a separate exhaust system.

The HVAC designer is required to get approval from the NIH Division of Safety regarding exhaust mixture compatibility to avoid cross contamination upon system failure or equipment damage due to an incompatible mixture.

As a minimum, supply air for these areas shall pass through a prefilter and on the upstream side of the AHU with efficiencies of 30% and 95% respectively based on ASHRAE Standard 52-76, atmospheric dustspot test efficiency. Special areas may require greater filtration on both the supply and the exhaust sides. The requirements for additional exhaust filtration shall be coordinated with the NIH Division of Safety, Occupational Safety and Health Branch and Radiation Safety Branch, where specific hazardous program functions occur.

High-efficiency particulate air (HEPA) filtration of supply air may be required for animal-holding rooms housing immunosupressed or transgenic populations or where populations are involved in chronic testing.

Specialty areas such as operating rooms, recovery, etc. may require higher filtration levels. The A/E shall assess the filtration needs for each function in coordination with research personnel.

In animal-holding rooms, supply air must be introduced through high-volume, ceiling diffusers and uniformly drawn across animal-housing areas to provide uniform mixing in the room. Where required a provision should also be made for high exhaust to be activated for direct exhausted cages to maximize the facility flexibility. Care must be exercised to ensure that the system does not create drafts on the animals and that the airflow is uniform in nature. Terminal velocity of discharged air 600 mm from wall surfaces must be less than 0.25 m/s, or in critical areas, 0.15 m/s at head height. Designer must follow the procedures detailed in Ventilation Design Handbook on Animal Facility and Animal Facility design published by NIH and ASHRAE Application Handbook.

Humidity control is critical in animal areas. Higher relative humidity in winter is often required for primates and certain other animals as compared with laboratories. Low-pressure, dry-steam direct injection humidification to introduce clean steam supplied by vaporizing softened water in a steam-to-steam generator shall be used for humidification.

D.16.10 Air-Handling Systems for Hospital Buildings

Hospital buildings are generally designed using recirculating-type HVAC systems with various percentages of required outdoor air.

Outdoor air ventilation rates shall be as defined under section D, Design Criteria of the Clinical Center Design Policy and Guidelines. Air-handling systems may be of the constant or variable air volume type provided that minimum total occupied air change rates are maintained. Systems shall automatically compensate for filter loading and pressure changes. Pressure-independent hot water terminal reheat devices shall provide individual space temperature control. The HVAC system shall be designed to maintain the proper temperature, humidity, differential pressure, outdoor air exchange rate, and acoustic criteria with the space. The HVAC system capacity shall be based on the largest of the following parameters:

- The amount of total supply air required to satisfy the specific outdoor air exchange rate for each of the various program functions

- The required space-cooling load, which is primarily a function of thermal transmission, solar loads, associated medical equipment, occupant load, and lighting loads. At the NIH, a combined nominal equipment and lighting load density of 54 W/nm^2 shall be used as a minimum in design of hospital areas 22W/nm^2 for equipment, 32 W/nm^2.

HVAC system design for specialty areas such as intensive care units, surgery suites, radiology rooms, cystoscopy rooms, treatment spaces, etc. shall be based on actual loads and design conditions. The A/E shall thoroughly review the program of requirements to understand the scope and magnitude of miscellaneous spaces.

Hospital buildings shall be supplied with multiple manifolded AHUs such that, upon failure of any major component related to an AHU, the remaining available HVAC air-handling equipment will provide 100% capacity. A parallel system design using two or more pieces of air-handling equipment which operate simultaneously to meet full-load conditions is the preferred choice to ensure overall system reliability. Each AHU and its related components shall be capable of being totally isolated from the remaining operational units to accommodate routine maintenance and emergency repairs in the event of equipment failures.

D.16.11 Critical Use Areas

Critical use areas such as operating and cystoscopy rooms shall have dedicated air-handling systems that are backed up by the central units for redundancy. Each operating or cystoscopy room shall have an individual temperature, humidity, and pressurization control.

The dedicated supply, return, and exhaust air system serving critical use areas shall automatically transfer to emergency power in the event of normal power failure. The supply air system shall be single duct with unlined, pressure-independent, constant- volume hot water terminal reheat devices and low-velocity terminal ductwork.

The AHU serving critical use areas shall have prefilters, filters, a heating coil, a cooling coil, and a central humidifier (to raise the humidity level to 40% RH). The final filters shall be located on the discharge side of the supply fan and humidifier with a diffuser section in between to ensure the uniform distribution of airflow over the filter surface.

The supply air duct on the downstream side of the final filters shall have air-tight access panels at each elbow and at 6 m intervals on straight duct runs for cleaning and inspection. The air distribution for each operating room shall have perforated laminar flow panels positioned around the operating table to maintain a vertical low-velocity, laminar distribution. A minimum of two exhaust registers in each operating room shall be located diagonally opposite and 7 in. above the finished floor. The exhaust air quantity shall be at least 15% less than the supply air to maintain positive pressure between the operating room and the adjoining areas.

The individual humidity for each operating room shall be maintained by a terminal humidifier on the downstream side of the dedicated constant-volume reheat terminal unit serving the space.

Terminal HEPA filters shall be considered for use downstream of terminal humidifiers for each operating room.

Each operating room shall be furnished with temperature and humidity recorders to keep a continuous record of ambient conditions. In lieu of the chart records, temperature and humidity sensors can be used to record data at the Building Control Center.

Where deemed necessary by program requirements, other areas such as intensive care units, isolation suites, and evasive procedure rooms may also be served by critical use AHUs.

D.16.12 Air-Handling Systems for Administration Buildings

Air-handling systems for administrative, office, conference, and other general use facilities are similar in design. They frequently employ VAV with terminal zone- or room-heating units. These systems are recirculating type with ventilation rates designed to meet ASHRAE Standard 62-1989. Air side dry-bulb economizers provide free cooling when ambient conditions permit.

Air-handling systems for administration buildings are best kept simple and zoned consistent with the building use and occupancy schedules. Large conference or assembly areas with intermittent use shall not be connected to units that supply routine office space.

Air-handling systems found in these buildings may have the following features:

- Single supply and return fans without redundant components
- Night setback and morning warm-up control modes
- Mixing plenums with minimum and maximum outdoor air dampers to accommodate minimum ventilation and economizer operations
- 30% efficient prefilters and optional 60% efficient after- filters
- Preheat coils to support morning warm-up functions
- Draw-through chilled water coils
- Central AHU humidifiers only
- Medium-pressure duct distribution to terminal control devices
- Fully ducted return air system with building pressure- controlled

relief devices

Computer or data processing facilities are commonly found in administration buildings and require special consideration.

HVAC systems for central computer rooms must meet the special requirements for lower temperatures, controlled humidity, and extremely high reliability. The suggestions listed below are excerpted for the ASHRAE *Handbook for HVAC Systems and Equipment* and they shall be taken as requirements unless the program dictates specific equipment requirements that need to be further considered.

The typical computer room design conditions temperature setpoint and offset shall be 22 +/- 1^{o}C; the RH setpoint and offset shall be 50 +/- 5 +/-5%; filtration shall be 45%, minimum 20% based on ASHRAE's dust-spot efficiency test.

A sensible heat ratio, approximately 0.9 to 1.0, is common for computer room applications.

The air-handling apparatus should be independent of other systems in the building, although it may be desirable that systems be cross connected, within or without the data processing area, to provide backup. Redundant air-handling equipment should be evaluated.

The refrigeration systems should be independent of other systems and should be capable of year-round operation. It may be desirable to cross connect refrigeration equipment for backup, as suggested for air-handling systems.

Fire protection for the air-conditioning system should be fully integrated with fire protection for the computer room and the building as a whole.

Computer room systems are attractive candidates for heat-recovery systems because of their large, relatively steady year-round loads.

Administration buildings traditionally have large glass areas with a large diversity of load based on the exposure and occupancy. Careful consideration to the number and placement of terminal control devices is required. Each unique room shall have a separate point of control. Rooms which are similar in size, use, occupancy, and exposure may be combined on a single point of control.

Perimeter radiation should be considered where large glass areas exist and where furniture layouts place seating adjacent to perimeter walls. The controls of radiation shall be fully coordinated with other terminal control units so that simultaneous heating and cooling does not occur.

Toilet rooms, janitor facilities, pantries, copy rooms, and other miscellaneous spaces require exhaust to remove odors and heat from occupied areas. Toilet rooms and janitor closets shall be connected to common exhaust systems and be designed to run continuously. Other exhaust may be connected to general exhaust systems which are controlled to operate when central air-handling equipment is operational.

D.16.13 AHUs and Components

The type and construction quality of AHUs approved for use in NIH buildings are based on several factors, such as size, system features, building types, site restrictions, etc. The Project Engineer must carefully review the project design criteria to establish the most cost-effective equipment that provides, throughout the system life, stable and continuous operation. Major unit components shall not require replacement until the system life is realized. The following guidelines shall be utilized in the design and specification of AHUs:

- Air-handling systems that are generally small in capacity (less than 9440 L/s), utilize return air, and are not serving critical program functions may be factory-packaged, institutional-grade units.

- Large, central station AHUs (greater than 9440 L/s) that are recirculating or use 100% outdoor air shall be custom-designed, factory-fabricated and -tested units.

- Large, central station AHUs designed for installation in existing buildings where access is restricted or designed for new buildings where the construction phasing does not permit the installation of large factory-fabricated sections shall be custom-designed, field-erected and -tested units.

The Basis of Design report submitted by the A/E shall define the type and quality of air-handling equipment proposed for use during design. The report shall provide justification for equipment selection by the A/E.

Factory-packaged, institutional-grade AHUs, when approved for use, shall conform to the following criteria:

- Units shall be of a modular design and have double-wall casing for all component sections.

- The unit's coil capacity must be able to handle up to 100% outdoor air when required without moisture carryover.

- All unit components must have large access doors to permit inspection, routine service, and cleaning.

- Unit casings shall be pressure rated for the total system design operating pressure plus 25%.

- Fan sections, where possible, shall employ airfoil fans with a minimum ACMA Construction Class of II.

- Fan sections shall be isolated from the remaining unit and the connecting duct system to control vibration.

- Solid fan shafts only will be considered.

- External fan motors are preferred, and in all cases bearing lubrication lines shall be piped exterior to the casing wall.

- Fan volume may be led control using either inlet vanes or variable frequency fan drives.

- Units may be either draw-through or blow-through arrangements.

- Coil drain pans shall be stainless steel and have a positive slope-to-drain connection.

- Factory filter/mixing boxes may only be utilized for low-outdoor-air units and where filtration is limited to 30% prefilters.

- Built-up filter/mixing sections utilizing high-quality low-leakage dampers and filter frames installed within insulated metal casings are preferred.

Custom-designed, factory-fabricated AHUs shall be based on A/E Contract documents and built to specific dimensions indicated thereon. The Project Engineer shall lay out, in sufficient detail, the desired arrangement of each complete unit showing all required components, access doors, casing openings, service clearances, and overall dimensions. Layouts shall include sections to define the overall height and vertical location of duct connections, dampers, louvers, etc. The factory-fabricated unit shall be capacity and pressure tested as a completed unit at the factory before shipment. Custom-designed units and related air-handling system components shall conform to the following criteria:

- Units shall be custom engineered and preassembled at the factory on a structural steel base. The units shall be shipped as one piece if possible or in as few sections as possible. The number of field-casing joints shall be reduced at all reasonable cost.

- Casings shall be factory fabricated and double walled with structural, acoustical, and thermal performance certified by testing data. Casings generally have a solid exterior shell with a perforated interior shell upstream of final filters and cooling coils. A solid interior shell occurs downstream of final filters and cooling coils

- Casing access doors are required for both sides of heating/ cooling coils, fans, filters, dampers, sound attenuators, heat recovery devices, humidifiers, and any other component requiring routine service. Access doors where possible shall be man sized (600 mm x 1,829 mm), have vision panels, and seal with the air pressure.

- Each AHU component sections shall be supplied with suitable vapor-tight lighting to permit maintenance functions. Lights are typically controlled from a pilot switch located adjacent to the access door.

- Unit louvers shall be ACMA rated and selected for low-pressure drop with less than 0.003 kg/m^2 penetration at 3.8 m/s free-area velocity. Areaways for louvers shall have a minimum of two drainage points sized for full capacity. Areaway floors shall be sloped minimum 8% to drain.

- Dampers shall be low leakage, and opposed or parallel blade as required to accommodate mixing of airstream. Opposed blade dampers are required for nonmixing applications. Particular attention shall be given to achieve good mixing of outdoor and return air to minimize stratification and freezing of water coils. Air blenders shall be considered for use when airflow arrangements do not support the effective mixing of different airstreams.

- Air filters may consist of bag- or cartridge-type elements; roll filters are not acceptable. Their design face velocity shall not exceed 2.5 m/s nor shall manufacturers standard nominal ratings be exceeded. The preferred filter face section dimensions are 600 mm x 600 mm. Outdoor air and return air as applicable shall pass through prefilters. Large filter banks shall have intermediate supports to prevent bank deflection at maximum design pressure differentials.

- Minimum 30% efficient filters shall be installed upstream of any heat recovery device.

- Preheat coils may be glycol, hot water, steam, or steam with an integral face and bypass damper. All coils shall have copper tubes with aluminum fins and galvanized casing. Steam coils shall be drainable with vertical tubes and vacuum breakers. Glycol coils are generally preferred over hot water coils for added freeze protection. Hot water coils shall have duplex coil-circulating pumps on a return line with automatic lead-lag control in the event of a pump failure, isolation check valves, 100% emergency power. An individual starter shall be provided for each pump.

- Cooling coil velocity shall not exceed 2.5 m/s at maximum future and present design conditions. For new buildings coil shall be sized for a nominal face velocity not to exceed 2.0 m/s so that future growth can occur. Coils shall have copper tubes with aluminum fins and stainless steel casing. Intermediate stainless steel drain pans shall be provided for each coil bank more than one coil high. The cooling coil section shall have a stainless steel drain pan and a positive slope-to-drain connection. Pan drains shall be properly trapped. For draw through units where drain pan is on the fan side, to counter the negative pressure on the trap relative to the outside, the trap height must account for the static pressure in the reverse direction. In case of blow over units with the drain pan on the discharge side of the fan, the trap height must be sufficient to account for the static pressure in the unit. Static pressure conditions accounting for the dirty filter must be used to calculate the trap height. For correct design of trap, methods detailed in ASHRAE transcripts Vol.91 Pal B, 1985, pp 611-622" Criteria for Human Exposure to Humidity in occupied Buildings" and AMCA publication 201-90 "Fan and Systems" should be followed. Designer may also consult Trane Commercial and Comfort standards for their guidance.

- AHU fans may be vane-axial, airfoil centrifugal (single or double width), or plenum fans as justified by life cycle costing. Fans shall have a minimum ACMA Construction Class of II. Fans shall be totally isolated from the unit using inertia base and spring isolation. Fan volume control may be achieved using controllable pitch vanes on axial fans and either inlet vanes or variable frequency drives on centrifugal and plenum fans. Discharge dampers are not suitable for volume control. Fans may be arranged in either the blow-through or draw-through position. Redundant or parallel fans shall be installed in separate compartments and be capable of complete isolation.

- Where possible, sound attenuators shall be integrated as a part of the AHU. The large cross-sectional area of most units results in low attenuator velocity and a corresponding pressure drop while maximizing attenuator performance. The silencer rating shall be determined in a duct-to-reverberant room test facility which provides airflow in both directions through the test silencer in accordance with ASTM

Specification E477.

- Custom units must be designed to be totally isolated from other adjacent units so that routine maintenance can occur with the unit off and other units operational. Ultra-low leakage, industrial-quality isolation dampers shall be installed at the discharge of manifold units.

- Each AHU section shall be provided with drainage facilities that permit the washdown of units and contain leaks resulting from coil failures.

- Casings shall be constructed in a water- and air-tight manner. The manufacturer's standard cabinet construction shall result in an ASHRAE/ANSI Standard 111-88 leakage class of less than 9 for demount units as measured in accordance with ACMA Standard Z10-85. The fully assembled unit shall have a maximum air leakage rate of 1% of the supply air volume.

- Custom-designed, field-erected AHUs shall be similar in many respects to those which are factory fabricated. These units basically arrive at the job site as individual components that must be assembled on concrete pads or curbs to form the unit. Casing construction quality and erection procedures are extremely important on these units. Poor quality casings result in excessive AHU leakage and poor system performance. Contractor-shop-fabricated casings are prohibited.

- When heat recovery equipment is used, the heating and cooling coils shall be designed to function at full load with and without energy recovery. All coil schedules shall show both entering air conditions. Units with heat recovery systems shall be designed such that devices could be out of commission without any interruption to AHU system operation.

Humidifiers for central station AHUs shall be of the dry-steam, manifold-jacketed or Panel steam humidifiers (Atomizing Steam Humidifier) type and be located in the duct system where possible. Ductwork within the absorption range of the humidifier shall be fully welded stainless steel and pitched to drain. Steam lines serving humidifiers shall have an automatic isolation valve and be dripped to remove condensate prior to manifold. The isolation valve shall be closed during cooling mode to prevent additional heat gain in the duct system. A high-limit humidity controller must be provided for each humidifier.

The installation of heating and cooling coils in AHUs often creates long-term maintenance problems. Coils installed in either factory-packaged or custom-designed units, if not properly engineered, will not be serviced and will eventually fail to perform. The following issues shall be specifically addressed for all coil installations:

- Individual coils must be fully accessible on both the upstream and downstream sides to permit inspection and cleaning.

- The cooling-coil face velocity must be limited to 2.5 m/s across the entire face area to prevent carryover at maximum future and present design conditions. Air distribution plates should be considered for use upstream of coils, but plates must not induce a high pressure drop.

- Moisture eliminators may be considered where carryover presents a problem; however, eliminators must not impede service access to the coil surface for cleaning.

- Multiple coils are often required to provide the total capacity of individual units. Coils shall be a maximum of 3.0 m long by 0.91 m high and be capable of replacement without major rigging. Individual coils must be removable without disturbing pipe headers or other coils.

- Multiple coils shall be valved separately so that, if any individual coil fails, it can be isolated and drained while the remaining coils stay in operation. Return header for multiple-stacked coils shall be piped reverse return to assist a balanced water flow at all load conditions.

- All coils shall have integral vent and drainage ports. Steam coils shall be nonfreeze vertical tube where installation is possible and provided with steam vacuum breakers, not check valves located outside of the airstream.

- Even and consistent airflow across the entire coil surface is extremely important. Upstream mixing and the use of air blenders shall be carefully considered.

- Coil bank supply and return mains or steam and condensate mains shall have manual isolation valves so that the entire unit can be drained.

- Trainers shall be provided on the feed line for each coil bank. Control and balancing valves shall be installed on the return line for water coils. Balancing valves shall be specifically designed for balancing and have integral memory stops. Combination balancing, shutoff, and flow meter devices are not acceptable.

- One-third and two-thirds steam control valve arrangements with a manual bypass valve should be considered for large steam coils to improve control and operating efficiency. Steam mains shall be dripped prior to control valves.

- Float and thermostatic traps shall be used on steam coils. Trap bypass lines shall not be used; dual traps may be considered.

- Steam coils must be piped for complete gravity drainage and fitted with vacuum breakers. Vacuum breakers shall be located external to the air-handling casing. Condensate shall not be lifted downstream of steam coils. Condensate lines shall not be designed to discharge under pressure. There shall be a hydraulic head between the coil and steam trap of 450 mm minimum.

- Factory-packaged units shall have offset coil pipe headers to allow individual coils to slide out of unit casings.

- Face and bypass coil arrangement used for temperature control in AHUs have not performed well at the NIH, nor have they provided the level of performance needed for proper operation. Integral face and bypass steam coils are preferred over standard face and bypass coils.

- Hot water preheat coils shall be designed for parallel flow-circuiting. The counterflow circuiting, particularly with long coils, is dangerous because the cold air is in contact with the coldest water. Hot water flow shall be maintained through the unit by a pump system in conjunction with use of a three-way control valve and a minimum of 40% glycol mixture as an antifreeze solution during freezing weather.

The A/E shall give careful consideration to the location of the supply air fan with respect to coil banks. Excessive air velocity stratification across the face of a coil may affect the capacity, pressure drop, and water carryover characteristics. Thus, the location of the fan with respect to the coil bank is very important. Generally, if the air velocity across the coil does not vary by more than +/- 10% of nominal, essentially full capacity will be achieved and water carryover will not be a problem. However, if the air velocity stratification is greater than this, capacity reduction, carryover, and freeze-up problems could occur. When space limitations dictate that the fans be placed in close proximity to the heating or cooling coils, the following criteria should be used to determine the minimum distance between fan and coil for field built-up systems:

Draw-through System: For single-width fans, the distance between the fan intake and coil should be a minimum of one wheel diameter. For double-width fans, the distance between the fan intake and coil should be a minimum of 1/2 wheel diameter.

Blow-through System: Most problems occur in this type of system. To minimize space requirements, it is desirable to place the coil as close to the fan as possible. The minimum distance for satisfactory operation is a function of the dimensional relationship of fan to coil, the fan outlet velocity, coil face velocity, and coil pressure drop. An empirical formula that has been developed and seldom used correlates well with tests over the normal range of operating conditions found in blow-through applications:

$VP_E <$ .4 $(P_c + VP_c)$ for cooling-coils where $K \geq 27$

$VP_E <$ .25 $(P_c + VP_c)$ for heating coils where $K \geq 5$

$VP_E =$ velocity pressure at coil face, Pascal

$Vp_o =$ fan outlet velocity pressure, Pascal

$$Vp_o = \left| \frac{\text{coil face velocity}^2}{\text{outlet area x } 4005} \right|$$

$P_c =$ coil pressure drop based on nominal coil face velocity, inch water group

$Vp_c =$ velocity pressure corresponding with coil face velocity, inch water gauge

$$Vp = \left| \frac{|\text{coil face velocity}|^2}{4005} \right|$$

K= ratio of pressure drop of coil to velocity pressure at coil face velocity

$$K = \frac{P_c}{Vp_c}$$

The equations imply that the velocity pressure at the coil face must be less than 40% of the combined coil static pressure drop and coil velocity pressure on cooling applications and less than 25% on heating applications. This can be achieved by selecting a low outlet velocity, locating the fan far from the coil, and ensuring high oil pressure drop. The relationship between the velocity pressure entering the coil (VP_E) and the fan outlet velocity (VP_O) is a function of the distance of the coil from the fan and the fan size where L = distance from the fan discharge to the coil in meters, and D = .8 x fan outlet in square meters. These formulas work quite well over the practical application range. However, with low outlet velocity and high coil pressure drop, the formula would allow the coil to be placed right at the fan discharge. Thus a minimum distance of 1/2 fan diameter should be used.

A practical example is that to design a 1000 mm DW fan for a double-duct application where space is at a premium. Assuming that the fan in question is discharging into a plenum and the coil configuration is a typical arrangement, the closest location of the coils to the fan for satisfactory performance will be:

Given: 52,864 L/s, 4 row series 15 coil, Coil face velocity = 28 s Fan outlet velocity = 15.2 m/s, Fan outlet area = 0.35 m^2

$$\frac{VP_E}{Vp_o} = 0.4 \text{ x } \frac{(P_c + Vp_c)}{Vp_o}$$

P_c Assume coil pressure drop the catalog = 162 Pascals at 2.8 m/s

$$Vp_c = \frac{2.8^2}{1.29^2} = 4.71 \text{ Pa}$$

$$Vp_o = \frac{15.2^2}{1.29^2} = 139 \text{ Pa}$$

$$K = \frac{P_c}{Vp_c} = \frac{162}{4.71} = 34.4$$

Using the cooling coil equation

$$\frac{VP_E}{Vp_o} = 0.4 \times \frac{(162 + 4.71)}{139} = 0.47$$

$$\frac{VP_E}{Vp_o} = 0.47, \; L/D = 0.85$$

$L = 0.85D = 0.85 \times (0.8 \times 0.35) = 0.24$ m = minimum distance

Working this same formula with an eight-row Series 18 coil with 498 Pa of pressure drop results in a minimum distance of 450 mm. However, this is less than the minimum of 1/2 fan diameter of 750 mm in this case. When the coil must be located closer than this formula would allow, baffles can be added on the face of the coil to increase their pressure drop to the required valve determined from the formula. Another possibility, which is usually reserved for field fixes, involves the installation of a baffle plate. A baffle plate with 50% free area should be placed two-thirds of the distance from the fan discharge to the coil. This baffle plate should have an overall area equal to four times the area of the fan outlet and be approximately the same shape. The pressure loss across this baffle will vary, of course, depending on the distance between the fan discharge and coil and the fan outlet velocity.

The Contract documents should specifically address the placement of the fan with respect to the coil. Whenever possible, the fan should be placed with the outside of the fan scroll at or near the top or bottom of a coil bank.

Fans: Fans shall be individually selected for their specific application on NIH projects. Many different fan types and arrangements exist in the marketplace from a large variety of manufacturers. The Project Engineer has the responsibility to select the fan and specify its requirements to meet the functional needs of the system while providing stable, efficient, and quiet operation. Fan selections shall be based on the lowest reasonable speed while optimizing efficiency. Fan selections shall consider longevity of components, especially bearing life at maximum design conditions.

Inlet vanes maybe considered for use to vary air volume. The A/E shall evaluate the effects of low-frequency radiated noise on the system. During periods of normal building occupancy, most systems typically operate in the range of 50%-80% design capacity. Therefore, the fan that has been selected on the basis of 100% design capacity will be functioning most often at a throttled or reduced capacity. As air volume is reduced, this results in an increase in fan-generated noise. An example is an application in which the pressure rise across the fan at design capacity may be 1121 Pa, and the system static-pressure controller is set at approximately 374 Pa. Under these conditions, a commercial-quality, airfoil double-inlet double-width fan seldom achieves a static efficiency greater than about 60% even with the inlet valves set a full-open position. It is the presence of inlet vanes, even when in the full open position, that limits the achievable fan static efficiency. As the inlet vanes close to reduce air capacity from100 percent to, for example, 65% of design, the operating fan efficiency drops dramatically. At 65% of the design, the air horsepower developed by the fan (proportional to air volume x total static pressure) is only about 40% of that produced at design capacity. However, using inlet vanes to modulate flow the reduction in brake horsepower is only about 12%. This condition is the result of the changes in the shape of the fan-characteristic curve that occurs with orientation of the inlet vanes. These changes result in a decrease in fan static efficiency from an initial value of about 60% to approximately 37%. This significant change in fan efficiency has an enormous effect on fan-generated noise. Rather than a reduction of 6 dB, which might have been expected before the lower air volume and total static pressure, an increase of about 6 dB will occur due to the decreased fan efficiency. This increase in noise level typically appears in the low-frequency region of the spectrum and is perceived by the ear as an increase in the level of system rumble. Furthermore, at this reduced airflow condition the masking level of diffuser-generated noise is typically about 10 dB lower than at maximum design airflow. Thus, with the beneficial mid- to high-frequency masking noise significantly reduced, the occupant's perception of low-frequency rumble will increase.

All fans must be fully accessible for service and routine maintenance. Fan motors and drives shall not be located within hazardous or contaminated exhaust airstreams. Fan bearings where possible shall be serviceable outside of hazardous or contaminated exhaust airstreams. Inline fans with motors or drive exposed to exhaust airstreams are not permitted.

Fan systems designed for parallel or manifold operation shall be protected against backward rotation of fan wheels. Antirotation devices, motor brakes, or other approved methods shall be considered for use on these systems. Solid fan shafts shall be furnished whenever possible as an option.

Provide fans having a certified sound and air rating based on tests performed in accordance with ACMA Bulletins 210, 211A, and 300. See AMCA Standard 99, *Standard Handbook*, for definitions of fan terminology. The arrangement, size, class, and capacity of all fans shall be scheduled on the contract drawings for permanent records.

All fans shall be statically and dynamically balanced by the manufacturer and shall be provided with vibration isolation. Fans shall not transmit vibration to the duct system or building structure. All fans 18.7 kW and larger shall also be dynamically balanced in the field by the manufacturer after the installation is complete.

Diffuser cones and inlet bells are not permitted in rating a fan unless they are an integral part of the fan design.

Inlets and outlets of fans not duct connected, including fans in plenum chamber or open to the weather, shall have heavy OSHA-approved guard screens to protect personnel. Guard screens shall not impair fan performance and, when bolted to equipment, will permit their removal for fan service and cleaning.

Complete fan lubrication facilities shall be provided, such as oil reservoirs, sight glasses, grease and relief fittings, fill and drain plugs, pipe connections, etc. The facility shall be placed in a readily and safely accessible location so that after installation they will perform the required function without requiring the dismantling of any parts or stopping equipment. For fans located within AHU casings, lubrication facilities shall be piped to the exterior casing wall.

All parts of fans shall be protected against corrosion prior to operation of the fan. Exhaust fans shall be specifically addressed, as the airstream may contain excessive moisture, fumes, corrosive vapors, or contaminated or hazardous particles. Special consideration shall be given to those fans handling explosive vapors or radioactive material.

Certified performance data including acoustical data shall be submitted for each fan at maximum design conditions. Data shall include published sound power levels based on actual tests on the fan sizes being furnished and conducted in accordance with current AMCA standards. Such data are to define sound power levels (PWL) (10^{-12} W for each of the eight frequency bands). The acoustical design of the fan system must conform with the space noise criteria. Fan curves shall be submitted which will depict static pressure, total pressure, brake horsepower, and mechanical efficiency plotted against air volume. Fan curves shall include estimate losses for field installation conditions, system effect, and actual installed drive components. All included losses shall be defined on the fan curves. Data may also be submitted in tabular form, but tables are not a substitute for actual performance curves.

Each motor-driven fan shall be equipped with a V-belt drive, except those which are direct drive by design. Where factory-designed and-assembled belt drives which do not conform to the following are proposed to be furnished, such nonconformity must be noted on the shop drawing submittals and may be cause for rejection of the item. OSHA-approved mesh-type guards shall be provided for all belt drives.

Each drive shall be selected according to the rating and recommendations of the manufacturer for the service with which used, giving proper allowance for sheave diameter, center distance, and arc of contact less than 180 ^{0}F. The motor drive shall have a centrifugal fan, with forward curved blades, and with a nameplate rating of not less than 5% above the total of actual fan brake horsepower and drive loss at specified capacity.

Belts shall be constructed of endless reinforced cords of long staple cotton, nylon, rayon, or other suitable textile fibers imbedded in rubber. The belt shall have the correct cross section to fit the sheave grooves properly. Belts shall be matched carefully for each drive.

Extended-horsepower belts are not acceptable.

Motor sheaves shall be adjustable pitch type for 18.7 kW and less, selected so that the required fan rotational speed will be obtained with the motor sheave set approximately in midposition and have the specified pitch diameter in that position. Fixed-pitch sheaves shall be installed on fans 22.4 kW and larger. All multiplex belt drive assemblies regardless of horsepower shall be fixed-pitch type. Variable-pitch drives shall be used for all fans to accommodate initial fan balancing and converted to fixed-pitch where required when balancing is complete.

Fan motors shall have the capacity needed to operate the equipment at the specified midposition operating condition. Where nonoverloading motors are specified, the motor capacity rating at the most closed position of the motor sheave shall be selected. In no case shall motors be a smaller size than that required to operate without overload.

Fan sheaves shall not be smaller in diameter than 30% of the fan wheel diameter.

Sheaves shall be constructed of cast iron or steel, bored to fit properly on the shafts, and secured with keyways of proper size (no set screws). Keyways may be omitted for sheaves having 15 mm or smaller bores, where set screws may be used.

Fans shall be furnished complete as a package with motors, drives, curves, bases, and inlet and outlet fittings. Detached vibration isolation devices may be provided separately.

Duct Design and Components: The duct system design for NIH buildings shall consider space availability, space air diffusion, noise levels, duct leakage, duct heat gains and losses, balancing methods, fire and smoke control, initial investment cost, and system operating cost.

Deficiencies in duct design result in systems that operate incorrectly or are expensive to own and operate. Poor air distribution can cause discomfort; lack of sound attenuation may permit objectionable noise levels; poorly designed sections of ductwork can result in an unbalanced system; faulty duct construction or lack of duct sealing produces inadequate airflow rates at the terminals; and insufficient duct insulation leads to excessive heat gain or loss and contributes to condensation problems.

The duct system design shall be based on ASHRAE and SMACNA standards. Duct construction shall be suitable for the operating parameters of the system and be tested to prove compliance with project specifications.

Fans in the field typically show a lower performance capacity than manufacturers' ratings. The most common causes of deficient performance of the fan/system combination are improper outlet connections, nonuniform inlet flow, and swirl at the fan inlet. These conditions alter the aerodynamic characteristics of the fan so that its full flow potential is not realized. One bad connection can reduce fan performance far below its rating. The Project Engineer must consider potential field conditions and performance penalties in the final selection of fans.

Normally, a fan is tested with open inlets and a section of straight duct attached to the outlet. This setup results in uniform flow into the fan and efficient static pressure recovery on the fan outlet. If good inlet and outlet conditions are not provided in the actual installation, the performance of the fan suffers. To select and apply the fan properly, these effects must be considered, and the pressure requirements of the fan, as calculated by standard duct design procedures, must be increased.

To achieve rated fan performance, air must enter the fan uniformly over the inlet area in an axial direction without prerotation. Nonuniform flow into the inlet is the most common cause of reduced fan performance. Such inlet conditions are not equivalent to a simple increase in the system resistance; therefore, they cannot be treated as a percentage decrease in the flow and pressure from the fan. A poor inlet condition results in an entirely new fan performance. Many poor inlet conditions affect the fan more at near-free delivery conditions than at peak pressure, so there is a continually varying difference between these two points. Adequate space must be provided by the engineer so that fan layouts can accommodate ideal inlet conditions. Poor fan layouts result in increased operating cost and deficient performance.

Since duct systems can convey smoke, hot gases, and fire from one area to another and can accelerate fire within the system, fire protection is an essential part of air-conditioning and ventilation system design. NIH guidelines and life safety codes require compliance with NFPA Standard 90A, which examines fire safety requirements for ducts, connectors, and appurtenances; plenums and corridors; air outlets, air inlets, and fresh air intakes; air filters; fans; electric wiring and equipment; air cooling and heating equipment; building construction, including protection of penetrations; and controls, including smoke control.

Leakage in all unsealed ducts varies considerably with the fabricating machinery used, the methods for assembly, and installation workmanship. For sealed ducts, a wide variety of sealing methods and products exists. Each has a relatively short shelf life, and no documented research has identified the in-service aging characteristics of sealant applications. Many sealants contain volatile solvents that evaporate and introduce shrinkage and curing as factors. Surface cleanliness and sealant application in relation to air pressure direction (infiltration and exfiltration) are other variables. With the exception of pressure-sensitive adhesive tapes, no standard tests exist to evaluate the performance and grade of sealing products. Project specifications and ductwork plans shall define the duct construction method and class, sealing materials, and acceptable leakage rates for each application. Duct pressure tests shall confirm construction quality and actual leakage rates.

Duct system design and air device selection and layout must consider the architectural aspects of the building. Ductwork must fit within the allocated space and not require the lowering of ceilings. Duct design must allow for easy adjustment and maintenance of required components. Air device locations must be coordinated with architectural reflected ceiling plan, bulkheads, lighting coves, and other special features. Air distribution systems are an integral part of the building and must be designed to meet the stated design criteria efficiently without generating noise, creating drafts, or causing thermal imbalances or poor IAQ.

Supply, return, and exhaust air shall be ducted for all spaces, i.e., not taken through ceiling plenums, shafts, mechanical equipment rooms, corridors, or furred spaces. Generally, the circulation of air directly between areas is not permitted, except into toilet rooms,

locker rooms, and janitor's closets. Circulation may also occur between adjacent corridors into negative pressure area or out of positive pressure areas. Makeup air for kitchens or other food preparation areas may come from adjacent dining areas since these areas are usually negative with respect to adjacent areas.
Conditioned air shall be supplied to corridors to maintain design temperatures and as required to make up exhaust through negatively pressurized rooms opening directly to the corridor. The quantity of conditioned air to the corridors shall be sufficient to maintain an overall positive building pressure.

The supply air distribution system must be designed to minimize turbulence and to avoid impacting the performance of primary containment equipment such as chemical fume hoods and biological safety cabinets. Therefore, perforated ceiling panels located away from the containment devices are recommended to provide even and low terminal velocity performance instead of grilles, registers, and ceiling diffusers. If ceiling diffusers are used, the device should be placed away from the front of the hood, the quadrant of the device which blows at the hood face should be blocked, and the throw velocity of device should be designed for no more than half to two-thirds of the hood face velocity.

Air distribution devices shall be selected for each specific application. Many different types and styles of air devices are available on the marketplace to meet the various performance criteria. Discharge velocity, diffusion pattern, throw, terminal velocity, volume control, noise generation, and appearance are factors to be considered in device selection.

Air devices shall be selected to provide a uniform, quiet, and low-velocity distribution covering the majority of the occupied area. Air devices shall not dump the air, create drafts, or generate turbulence within rooms. Certain areas may require laminar flow devices to keep contaminants controlled below work areas until they are exhausted. ASHRAE’s *HVAC Systems and Equipment Handbook*, Air-Diffusing Equipment chapter, reviews the general application of the various air devices.

The terminal velocity of discharged air 0.61 m from wall surfaces desirably should be less than 0.25 m/s. Where applications become more critical, such as for laboratories, vivariums, and treatment/ procedure rooms, the terminal velocity should not exceed 0.15 mps at 1.8 m above floor height.

Table 10 summarizes the acceptable velocities for HVAC components and duct systems. Louvers require special treatment since the blade shapes, angles, and spacing cause significant variations in louver-free area, pressure drop, and water penetration. Louver selections shall always be based on data obtained in accordance with AMCA standards.

Table No. 10.
Typical Design Velocities for HVAC Systems

Element	Face Velocity m/s
DUCTWORK	
Medium Pressure Mech Rooms/Shafts Occupied Areas	12.7 10.2
Low-pressureMech Rooms/Shafts Occupied Areas Terminal Outlets	7.6 6.1 3.8
Outdoor/Relief Air	7.6
COOLING/DEHUMIDIFYING COILS	2.5 Maximum
HEATING COILS	
Steam/Hot WaterUnit Ductwork Electrical	2.5-3.8 7.6 Maximum Per Mfg. Data
FILTERS	
Viscous Impingement	1.0 - 4.0
Dry Type, Extended-Surface Flat (Low Efficiency)	 Duct Velocity
Pleated Media	2.5 Maximum
HEPA	1.3 Maximum
LOUVERS	
Intake Exhaust	2.5 Maximum 3.8 Maximum

Ductwork may be either single- or double-wall construction as required to satisfy the acoustical requirements specified in these guidelines. Double-wall construction shall consist of a perforated liner surface with an approved film-covering acoustical material. Terminal unit sound attenuators having a similar construction to double-wall ductwork may be utilized for room noise attenuation. The use of internal sound lining is prohibited at the NIH.

Ductwork may consist of either round, flat-oval, or rectangular shapes as needed to suit the building. Duct fittings, joint methods, supports, and construction details shall meet the requirements of SMACNA. All fittings shall have documented flow loss coefficients by either SMACNA or ASHRAE. Irregular or makeshift fittings are not acceptable. Factory-fabricated fittings by independent manufacturers may be utilized provided they have catalogued performance criteria.

Flexible ductwork may be utilized for supply air application to connect air devices to low-pressure duct mains and to make the final connection to terminal units. Flexible duct runs shall be limited to 600 mm for terminal units and 1800 mm for air devices. Flexible ducts shall have a UL rated velocity of at least 20.3 m/s and a maximum UL-rated pressure of 2490 Pa positive. Flexible ducts must be factory insulated and comply with the latest NFPA Standards 90A and 90B. Flexible duct joints shall be made using stainless steel draw bands and manufacturer-approved tape.

The duct construction method, material of construction, and pressure classification shall be specified by the project engineer for each unique system installed on the project. Table 11 shows the minimum requirements for generalized applications in NIH buildings.

Table No. 11
Minimum Duct Construction Standards

Application	SMACNA Pressure Classification	Materials of Construction	Field Pressure Testing
Low-pressure Supply Ductwork	498 Pa POS	Galvanized Steel	No
Medium-Pressure Supply Ductwork Upstream of Terminal Units	1494 Pa POS	Galvanized Steel	Yes
Low-pressure Supply Ductwork Downstream of Terminal Units	498 Pa POS	Galvanized Steel	No
Low-Pressure Outdoor, Relief, Return Air Ductwork	498 Pa POS	Galvanized Steel	No
Medium-Pressure Return Ductwork Downstream of Terminal Units	747 Pa NEG	Galvanized Steel	Yes
Low-Pressure General Exhaust Ductwork	498 Pa NEG	Galvanized Steel	No
Low-Pressure Wet Process Exhaust Ductwork	498 Pa NEG	Aluminum or Stainless Steel	No
Low-Pressure Hazardous Exhaust Ductwork Upstream of Terminal Unit	498 Pa NEG	Epoxy-Coated Galvanized Steel or Stainless Steel	No
Medium-Pressure Hazardous Exhaust Ductwork Downstream of Terminal Units	CLASS I/INDUST. 1494 Pa NEG	Epoxy-Coated Galvanized Steel or Stainless Steel	Yes
Special Hazard Exhaust Ductwork	747 Pa NEG	Stainless Steel	Yes

Those duct systems requiring field pressure testing shall be tested at 125% of the duct construction rating. Pressing testing shall conform to SMACNA *High Pressure Duct Standards*, Third Edition, Chapter 10. The positive pressure side of any exhaust system installed within a building shall be pressure tested to 150% of the duct construction rating.

Wet exhaust ducts or those duct systems that tend to carry moisture shall be pitched toward the source of moisture generation. Drainage facilities shall be provided in these systems.

The term "hazard exhaust" generally applies to common exhaust systems serving laboratories, fume hoods, vivariums, biosafety cabinets, etc. that by their relatively light hazard rating may be exhausted by a common exhaust system.

The term “special hazard” generally applies to all other exhaust systems serving BL3, BL4, radioactive hoods, etc. that by their critical nature or extreme hazard must be exhausted individually and normally requires special filtration.

Wet-exhaust ductwork shall be of either aluminum or Type 304 stainless steel construction to prevent corrosion. Hazardous exhaust or special exhaust ductwork shall be at least Type 304 welded stainless steel or better as required to handle exhaust products.

D.16.14 Separation of Intakes and Exhaust

Outdoor air intake and exhaust discharges shall be located to avoid health hazards, nuisance odors, reduction in capacity of air-conditioning equipment, and corrosion of equipment caused by reentry of exhaust air from any source. The A/E shall ensure that no cross contamination will occur from exhaust discharges to outdoor air intakes.

Outdoor air intakes are classified as any louver, duct, gooseneck, ventilator, or pipe that is commonly used to take in outdoor air for the purpose of ventilation, heat removal, exhaust makeup, combustion air, air compressor makeup, or comfort conditioning. Exhaust discharge includes that from exhaust fans, vehicle exhaust, cooling towers, boiler or incinerator stacks, emergency generators, vacuum pumps, steam or other hot vents, plumbing vents, condensing units, kitchen hoods, relief from AHUs, and mechanical/electrical room ventilators.

Separating air intake and exhaust air outlets by at least 7.6 m as recommended by codes is a minimum requirement under normal conditions. Other factors such as wind direction, wind velocity, stack effect, system sizes, and height of building must be evaluated, and location of intakes and outlets shall be adjusted as required. The ASHRAE *Fundamentals Handbook* is a source for analyzing these factors.

A wind analysis performed by a qualified wind consultant is recommended to analyze and make recommendations on these factors. The primary building exhaust stack locations and heights shall be in concurrence with air dispersion modeling by the Special Project Office at the NIH.

The bottom of all outdoor intakes shall be located as high as practical but not less than 1.8 m above ground level, or if installed through the roof, 900 mm above the roof level.

Outside air intake shall be at least 12 m away from hot exhaust discharging horizontally or deflected down, plumbing vents, animal room exhaust, generator exhausts, loading docks, automobile entrances, driveways, passenger drop-offs, cooling towers, and incinerator and boiler stacks.

The A/E shall use data, formulas, and other design information as published by ASHRAE, ANSI, and other sources in designing the exhaust stack height and velocity characteristics to overcome the building cavity boundary and avoid reentrainment of exhaust. Stacks shall be shown as part of the architectural design and the design rationale described in the early design submittal. In general exhaust stacks shall:

- Be in a vertical direction at a minimum of 3 m above the adjacent roofline and so located with respect to opening and air intakes to avoid reentry of contaminants into any building

- Have a discharge velocity of at least 20 m/s.

- Be designed so that aesthetic considerations concerning external appearance are not allowed to overcome the above requirements and the safe discharge of exhaust

- Be designed so that, where possible, multiple-manifold exhaust fans have separate exhaust stacks to avoid a positive pressure condition on the dischargeable side of an inoperable fan

D.16.15 Exhaust Systems

NIH buildings typically contain a large variety of exhaust air systems that serve a multitude of program functions. The primary purpose of any exhaust system is to remove odors, vapors, hazardous materials, or other contaminants from buildings to protect the health and safety of building occupants. Exhaust discharge must be designed to prevent the reentrainment of exhaust back into outdoor air intakes.

D.16.16 General Exhaust Systems

The systems covered under this category are conventional, low-pressure, low-velocity types, serving toilets, locker facilities, janitor's closets, soiled utility rooms, laundries, and trash rooms. The general exhaust system also includes areas with 100% exhaust requirements dictated by ventilation standards. The specific examples under this classification are central sterile supply areas and kitchens.

General exhaust systems are generally simple in design with control limited to start-stop modes as a function of occupancy schedule. Systems are low-velocity without terminal control devices or redundant fans. General exhaust fans are typically supplied by normal power only.
General room exhaust air should be exhausted through ceiling registers located over heat-producing equipment such as copiers, refrigeration equipment, appliances, computer equipment, etc.

Wet exhaust from shower rooms and process areas is frequently handled by these systems. The moist air over sterilizers, glass/dishwashers, cage washers, and pot-washing equipment should be captured using canopy-type stainless steel hoods. Exhaust air shall be at a minimum rate of 254 L/s/m^2 of hood area. Canopy hood duct connections shall be fitted with moisture eliminators. Wet exhaust systems, where possible, shall be separated from other general exhaust, and ductwork shall be either stainless steel or aluminum pitched toward inlets for drainage.

Air may be exhausted from the corridor through toilet rooms, bathrooms, and janitor's closets if necessary. Exhaust air shall not be drawn directly from a public corridor through any storage room.

All kitchen or pantry hoods are furnished as dietetic equipment including the canopy hood over pot-washing stations. These hoods are furnished by the fabricators of the kitchen equipment and serve:

- grease producing equipment, such as: griddles, ovens, broilers, and deep-fat fryers

- hot vapor producing equipment, such as: steam kettles, vegetable steamers, and high-pressure cookers

The exhaust systems serving these hoods have the following specific requirements.

Filtered (30% efficient, Grade D) unheated and uncooled outside air shall be at the rate of 155L/s per linear meter of slotted perimeter of the hood as the make-up air to meet the exhaust needs. Assume a 37 Pa water-gauge static pressure drop through the hood.

The remaining makeup air at the rate of 232 L/s per linear meter of slotted perimeter of the hood should be derived from the environmental air supplied by the kitchen and/or dining room AHUs.

Exhaust of 387 L/s per linear meter of slotted perimeter using a dedicated exhaust fan for each hood 335.28 Pa static pressure drop through the hood shall be assumed. See NFPA Standard 90A and the NIH Master Standard Specifications for the specific requirements of duct velocity, access, material, construction and routing.

Automatic operation shall be provided for the exhaust fan through the hood control panel (furnished with the hood) for washdown cycle and fire protection.

D.16.17 Laboratory Exhaust System

The laboratory exhaust system, where there is no mixture incompatibility, shall be arranged with multiple-manifolded fans designed to maintain 100% of exhaust design conditions at all times. The number of fans shall be determined by the A/E to accommodate physical and capacity restraints. One of the fans shall be provided as a backup for any other single fan. Upon the loss of flow through any one fan, the designated backup fan shall be energized to maintain a constant exhaust system flow. The fan designated as a backup shall be automatically alternated among all system exhaust fans so that all motors and equipment experience approximately the same running time. Exhaust fans shall be of industrial grade with motor and drives located out of the airstream. Each fan shall be fully isolated from the others to accommodate routine service while the overall system is operational.

The laboratory exhaust system shall account for filter loading (only where filtration is a requirement) and will generally combine general laboratory and fume hood and biological safety cabinet exhaust for maximum optimization of space and to achieve better dilution levels with acceptable concentration rates. The system can generally be designed to exhaust laboratory air and all fume hood exhaust through the same duct system.

Special exhaust systems for fume hood exhausts that cannot be combined with the general laboratory exhaust, such as exhaust from perchloric acid fume hoods and radioisotope hoods, etc., need to be identified early in the design process and incorporated into the design. Dedicated exhaust systems shall be provided for those applications.

The HVAC designer is required to get approval from the NIH Division of Safety or the designated safety officer regarding exhaust compatibility to avoid cross contamination upon system failure or equipment damage due to an incompatible mixture.

Exhaust air from laboratory equipment such as fume hoods and biosafety cabinets connected to a general central laboratory exhaust main is preferably controlled through pressure-independent terminal units.

Exhaust fan systems used for fume hood exhaust from laboratories or specifically for dedicated fume hood exhaust shall be designed, selected, located, and maintained in full accordance with ASHRAE recommendations and NFPA standards. The exhaust fan systems' flow and pressure shall be monitored by device and connected to the building automation system or otherwise to a visual alarm to alert Building Maintenance Office personnel upon loss of flow or pressure in the system. The alarm system shall also indicate failure of any single fan in the system.

If filters or scrubbers are required, they shall be located as close to the source of contamination as possible while maintaining ready access for installation, monitoring, and maintenance.

Smoke or fire dampers shall NOT be installed in laboratory exhaust ducts.

Supply fans shall be energized after exhaust fans are operational and exhaust flow is confirmed. Fire detection and alarm systems shall not be interlocked to automatically shut down laboratory hood exhaust fans except as formatted by NFPA Standards 45.

No positive pressurized segment of any laboratory exhaust system shall be located in any occupied zones. Offices within the mechanical rooms are classified as occupied zones. The design shall permit the installation of exhaust fans at the end of exhaust line and as close as possible to the final point of discharge to avoid or minimize leakage to the space, particularly mechanical areas. The positive pressure segment of exhaust system shall be constructed per SMACNA standard for 1494 Pa positive pressure. A leak test shall be performed to verify the SMACNA allowable leakage rate, as defined in the *High Pressure Duct Standard*, Third Edition, Chapter 10.

All toilet and general use exhaust shall discharge through a separate exhaust system.

Fume hood exhaust ductwork and exhaust fans shall be coated with a protective, corrosion-resistant coating or constructed of corrosion-resistant material, such as stainless steel or an epoxy phenolic coating, e.g., plastite, hersite, keysite, or vinyl selected for resistance to the anticipated exposures.

Exhaust stacks shall be located at highest part of the facility and positioned to prevent reentrainment of fumes at intake points. Exhaust discharge must be at least 3 m above the adjacent roofline and located to prevent reentrainment into outdoor air intakes. Discharge of laboratory exhaust must be vertical with exhaust velocity of (18.3 to 20.3) m/s at the point of discharge. Reentry calculations shall dictate the specific exit velocity.

Vertical exhaust shafts shall be combined in a plenum at the roof and exhausted with redundant exhaust fans in order to provide system reliability and to provide the ability to service one exhauster without system shutdown. Each exhaust fan shall discharge separately above the roofline. Fan discharges shall not be combined.

Fume hood air requirements will vary depending upon the selected manufacturer's requirement. Minimum face velocity of fume hood is 0.51 m/s across the maximum opening of the sash.

D.16.18 Vivarium Exhaust System

Exhaust systems employed in vivariums are similar in use and function to those in laboratory buildings. General system requirements are identical. The system shall exhaust all hoods and vivarium air through a common manifolded system. Systems shall be redundant, flexible, and reliable.

Exhaust air in general does not require filtration or scrubbing. However, exhaust as it leaves the animal rooms shall be filtered with a rough filter to capture hair and dander. A filter frame at low air exhaust that can hold a rough filter shall be provided from animal housing rooms. In special cases involving infectious animals a HEPA filter should be considered for use as directed by the NIH Division of Safety. These components shall be designed and selected for durability, easy maintenance, and replacement of filters.

Some special spaces in the vivarium facility, such as BL3 treatment rooms or holding rooms, may require special filtration. Requirements for these special facilities must be determined with the users and the NIH Division of Safety on a specific-project basis.

Exhaust grilles shall be located away from supply air diffusers in a manner that creates a uniform, low-velocity airflow across animal cages.

Points of connections to the vivarium exhaust system may be required for snorkels utilized to exhaust ventilated racks.

The vivarium exhaust system shall have a maximum air velocity of 7.5 m/s in exhaust ducts.

The vivarium exhaust system must be tied to emergency power so that ventilation continues in the event of a power failure.

D.16.19 Special Exhaust Systems

The special exhaust systems include dedicated exhaust systems for ethylene oxide (EtO) sterilizer, isolation rooms, autopsy suite, radioactive fume hoods, BL3 and BL4 facilities, and other miscellaneous functions as designated by the NIH Safety Officer. Each system has its unique set of requirements for air quantity, filtration, construction materials, type of discharge, controls, emergency power, hours of operation, etc.

In general, each special exhaust system shall have its own dedicated set of main and standby exhaust fan and ductwork not connected to any other exhaust system. To be in compliance with NFPA Standard, 90A, exhaust ducts from the special exhaust systems shall not be located in the same shaft carrying environmental supply and/or return air ducts.

A dedicated exhaust system for the autopsy/pathology suite shall have the following specific features:

- The exhaust fan shall be located at or near the roof with the fan discharging above the highest point of the building
- A HEPA filter shall be installed in the exhaust airstream at or near the exhaust fan. Redundant bag-in/bag-out HEPA filter banks with isolation dampers shall accommodate maintenance of filters
- A pressure-independent, constant-volume terminal unit shall be provided in the exhaust airstream to maintain constant airflow with the varying system resistance.
- Two wall-mounted exhaust registers shall be installed, one on each side of the sink, and one register above the top of the dissecting tables
- Ceiling exhaust air registers shall be located in the gross specimen storage room above the sink counter area to exhaust chemical fumes
- Room air near each autopsy table shall be exhausted by placing two wall registers approximately 175 mm above the finished

floor

- Approximately 24 L/s shall be exhausted from the cold room (mortuary refrigerator) when the room light is on. An interlock of the exhaust damper with the cold room door switch shall be provided

A dedicated exhaust system shall ventilate EtO sterilizer equipment, mechanical chase, floor drains, aeration units, and the cylinder storage areas. The exhaust system shall be separate from the general exhaust systems serving sterile processing areas. The exhaust systems shall operate 24 hours per day and maintain negative pressure in the areas housing EtO equipment even when the supply air unit shuts down during unoccupied hours, weekends, and holidays.

- The discharge air from the exhaust fans shall be released at the highest point above the building, and care shall be taken to ensure that the discharge air does not short-circuit and find a way into the intake of any AHU

- The systems shall be on standby emergency power

- The specific exhaust air intake locations listed above have different static pressure drops at the inlet. This information shall be coordinated with the equipment manufacturer, and pressure-independent constant-volume terminal units in each branch ducts, as required, shall balance the system

A dedicated exhaust system for isolation rooms shall be capable of producing either a room negative pressure (normal isolation) or a room positive pressure (reverse isolation). A selector switch with an indicator shall accomplish this mode. The isolation suite shall have a dedicated exhaust system composed of a roof-mounted exhaust fan, bag-in/bag-out HEPA filter, and pressure-independent constant-volume terminal units and balancing devices. The system shall be on standby emergency power.

The A/E shall use data, formulas, and other design information as published by ASHRAE, ANSI, and other sources in designing the exhaust stack height and velocity characteristics to overcome the building cavity boundary and avoid reentrainment of exhaust into outdoor air intakes or adjacent buildings. Stacks shall be shown as part of the architectural design and the design rationale described in the early design submittal. In general, exhaust stacks shall:

- Be in a vertical direction at a minimum of 3 m above the adjacent roofline and so located with respect to openings and air intakes to avoid reentry of contaminants
- Have a discharge velocity of at least 20.3 m/s
- Be designed so that aesthetic considerations concerning external appearance shall not be allowed to overcome the above requirements
- Concur in location and height with air dispersion modeling by the NIH Special Project Office
- Exhaust so that discharge from individual fans shall not be combined but ducted independently through the roof

D.16.20 Fume Hoods and Biological Safety Cabinets

NIH fume hood and biological safety cabinet specifications shall govern the requirements for specific types of hoods and cabinets. The A/E, after thorough review of program requirements, shall select hoods on cabinets that will meet the needs of the researcher, while optimizing system performance and minimizing energy cost. Current specification sections include the following:

- Section 11800: Fume Hood, Laboratory, Auxiliary Air Type
- Section 11810: Fume Hood, Laboratory, Air Bypass Type
- Section 11820: Fume Hood, Laboratory, Horizontal Air Bypass Type
- Section 11830: Fume Hood, Laboratory, Combination Sash Type
- Section 15991: Testing and Balancing of Laboratory Fume Hoods

The type of hoods employed for use at the NIH shall be based on a comprehensive life cycle cost analysis that accounts for all system features required by the Division of Safety. Variable or constant-volume hoods may be considered, but the health and safety of building occupants must not be compromised under either option. The ongoing maintenance cost of any option shall be considered in cost analysis.

Hazardous experiments involving toxic chemicals and/or unpleasant odors must be conducted within a chemical fume hood. Use of a chemical fume hood allows toxic materials and dust to go into the laboratory building exhaust system and be discharged to the outside.

A minimum system capacity is one 1200 mm chemical fume hood (nominal 3.54 L/s) for every other laboratory module. Distribution capacity shall be one 1200 mm chemical fume hood per laboratory module. The Program of Requirements shall govern whether the requirements are over this limit; these are the minimum design criteria.

The NIH Division of Safety shall be consulted to ensure that it has discussed the needs of the requestor and has determined the best containment device (fume hood, canopy hood, slot hood, trunk exhaust, downdraft table, etc.) for the research effort. All specialty-made or shop-fabricated canopy hoods, slot hoods, sprinkle exhaust, etc. shall be designed and constructed to the latest edition of industrial ventilation.

Auxiliary air-type laboratory hoods shall not be used in new laboratory facilities. These hoods should only be considered in the replacement of existing auxiliary air fume hoods and then only if they are continuously monitored with respect to air balancing.

In any fume hood retrofit application for existing facilities, the A/E firm shall verify existing system capacities inclusive of the auxiliary air and laboratory supply, and exhaust system characteristics. Once it has been assessed in coordination with the Maintenance Engineering Branch that the system(s) can support the addition or replacement of an existing bypass hood or auxiliary air hood, this information shall be documented and the design allowed to progress.

Note that auxiliary air hoods discharge untreated or partially treated air just in front of the face of the hood (usually at head level), and a scientist working at the hood must work in unconditioned air. Partial heating of the air supply in the winter reduces the economical advantage of this type of hood. If improperly balanced, some of the auxiliary air may not enter the hood but will enter the air-conditioned space of the laboratory, sweeping with it some of the contaminated air from the hood, which is an undesirable condition.

The laboratory air supply distribution system shall be sensitive to air motion within the laboratory space. Fume hoods rely primarily on face velocity through the hood's face to provide a safe working environment for the researcher.

To optimize the performance of the hoods, hoods need to be located away from interfering drafts, airflow disturbances, supply and exhaust, and pressure differentials created by the swing of doors. Personnel circulation characteristics in front of the hood's face need to be minimized.

New and existing chemical fume hoods shall have as design criteria a face velocity of 0.51 +/- 0.10 m/s with a uniform face velocity profile of +/- 10% of average velocity with the vertical sash fully open.

The A/E must realize in the early design phase that proper hood performance can only be achieved if the equipment is properly installed, the system is connected to a properly designed exhaust system, the supply system is capable of delivering the hood ventilation requirements, and the location of the hood has been properly selected within the laboratory area. For correct positioning of the Laboratory hood, the designer must follow the design methodologies to evaluate the likely hood containment performance detailed in NIH publication “Methodology for Optimization of Laboratory Hood Containment”

Improper assessment of any of these factors will result in poor hood performance which is not acceptable.

Fume hoods and biological safety cabinets at the NIH are used continuously; therefore they shall be “on” 24 hours per day, 7 days per week. In addition, there shall not be user control or nighttime setback control capability.

D.16.21 Variable Air Volume Hoods

VAV hoods may be considered for use in NIH buildings provided the following issues are evaluated and requirements met:

- The hood shall meet current fume hood specifications, with the exception that they are not the bypass type. However, partial bypass may be needed to meet minimum exhaust requirements for the lab to maintain face velocity at 150 mm sash height.

- The hood shall have no air-cleaning (HEPA or charcoal) or stack-sampling devices in the exhaust system (stack sampling is done on high-level-radiation hoods; biological cabinets have HEPA filtration). Varying the volume may interfere with the operation of this equipment or the current monitoring techniques used.

- The hood shall have no other auxiliary equipment (high-velocity-low-volume exhaust systems) on the same exhaust fan. This type of equipment is generally designed for a fixed volume and may not function properly if the volume of flow is decreased.

- The laboratory must remain under negative pressure with respect to the corridor or adjoining rooms even at the minimum exhaust rate, if negative pressure was part of the original laboratory design. When the exhaust quantity is reduced, the supply quantity must be reduced by the same volume.

- The laboratory must maintain minimum the required air changes per hour (six) with hood(s) in the minimum exhaust rate position.

- There shall be no extenuating circumstances based on hood and/or laboratory use which preclude the use of VAV systems. Examples of these circumstances might be (1) odorous compounds used on the lab bench and (2) excessive heat generation in the laboratory from process equipment or high-release compounds which require full exhaust rate dilution. All of these conditions might produce hazardous conditions if the exhaust volume is reduced.

- An airflow monitoring/alarm device must be installed at the hood to provide operating information to the hood user. The methods that are to be evaluated for monitoring the airflow will be (1) velocity sensing in the hood side wall, (2) sash position determination, and (3) pressure sensing between hood and room. One of the most suitable technologies shall be implemented.

- An override capability must be provided to allow the user to have maximum exhaust regardless of sash position.

- It is important for the hood user to know if the hood is a variable air volume hood and to understand how it operates.

- Control response time and stability should be reviewed to provide consistent repeatable performance.

- A constant face velocity shall be maintained at the fume hood sash at varying sash openings. The following methodology shall be evaluated to achieve the constant face velocity: (1) velocity measurement in the ductwork, (2) velocity measurement of the hood in the annular space between the outside and inside casing, and (3) direct sash position measurement. The analysis shall consider the following factors. First, the measurement of velocity pressure is difficult in the exhaust ductwork. The air velocity typically is very low, with correspondingly low-velocity pressure. In addition, the devices may become corroded if the exhaust stream contains material that will attack the sensor. Second, air velocity measurements in the annular space are sensitive to changes in airflow patterns in the room as well as in the hood. Finally, an option is to vary the sash position, which could be connected by a cable to a potentiom or other control system that transmits a signal to the volume control, which opens or closes the damper.

D.16.22 Fume Hood Testing And Alarms System

Fume hoods in new laboratory facilities shall have a pressure-independent flow-monitoring device connected to a local audiovisual alarm within the laboratory area. For existing facilities the implementation of airflow devices for fume hoods occurs during the renovation phase. When the fume exhaust falls below a preset safety level, the alarm will sound and the alarm light will come on.

All parts that are to be in contact with vapors/fumes in the hood, i.e, the sensing device, wiring, etc., shall be chemically resistant. All alarm systems shall be UL approved.

There shall be a means to shut off the audible alarm to reset. The alarm shall have an internal timer so that the audible alarm is reactivated after a specified time (adjustable between 5 minutes and 15 minutes).

The alarm shall have the capability to set the controller's setpoint to the safety level desired. There shall be means for setting the controller's setpoint to the exhaust level desired. This adjustment shall be “internal” so that it is not readily adjustable by operating personnel.

Upon return to normal flow, the alarm shall sound again until reset.

The ACGIH Guidelines are referenced in the guidelines for fume hood testing. The ACGIH requirements do not specifically address all testing issues required by the NIH. The following criteria shall be used for testing fume hoods in the NIH buildings:

The fume hood manufacturer, no later than 30 days after receipt of the order, shall provide to the owner a state-of-the-art fume hood test facility meeting the requirements of SAMA Standard LF 10-1980.

The hood manufacturer shall conduct ASHRAE Standard 110-1985 protocol of 1800 mm hood of similar design to the type specified. Both constant volume and variable volume Fume Hoods are acceptable The bypass shall be designed so face velocity does not exceed the maximum as the sash is lowered in variable volume hood. Variable Volume Fume Hood protocol of a 1800 or 1200 mm shall be tested in accordance with modified ASHRAE 110 Test for minimum base line requirements for the successful fume hood control system at the manufacturer's state of the art test facility meeting the requirements of SAMA standards LF10-1980 or latest on his cost for acceptance by NIH prior to delivery of hoods for installation. The minimum of 50% installed hoods at site will be again offered for testing on site by the contractor after installation and building balance prior to occupancy. Contractor shall arrange to conduct these testing by an NIH approved independent testing contractor. The specifications shall clearly identify type of measurement devices that maintains a constant face velocity; such as hot wire anemometer, heated thermocouple anemometer, impact tube and side wall or other static tap; pitot tube.etc. or by measuring volume or mass flow rate using devices such as office and differential pressure measurement system, nozzle and differential pressure measurement system, turbine flow meters swirl flowmeter and vortex shedding meter. Hood of similar design to the type specified the ASHRAE 110-1995 standard will have the following parameters for the purpose of this specifications.

D16.23 Laboratory Fume Hood Testing

Note: This first item goes in the balancing spec, the fume hood control spec, and the hood spec

FUME HOOD CONTAINMENT TESTING (On Site)

General: Laboratory areas and Variable volume fume hoods shall be tested as installed to assess the level of containment. Test identified below was created by Farhad Memarzadeh of the National Institutes of Health in 1997 and revised by Memarzadeh and Brighthill in 1999 and shall be performed during static and dynamic conditions. Testing shall be conducted as outlined below for 50% of the hoods provided in the project. Tests shall be characterized and referred to in two basic categories "Static" and "Dynamic". While elements of both static and dynamic testing exist in both test categories, these names are generally used for reference.

Static Testing: Testing shall be conducted in accordance with *ASHRAE 110 - Method of Testing Performance of Laboratory Fume Hoods* with the following modifications. This is primarily atest of the hood and laboratory configuration.

- Hoods will be tested with simulated apparatus. This apparatus will consist of: two each 3.8 L round paint cans, one 300mm by 300mm by 300mm cardboard box, three each 150mm by

150mm by 300mm cardboard boxes. These items will be positioned from 150mm to 250mm behind the sash, randomly distributed, and supported off the work surface by 50mm by 50mm blocks.

- The test gas will have a 6 LPM flow rate.
- Each test duration will be 5 minutes.
- Acceptable test results shall not exceed 0.05 **PPM**.
- At the conclusion of each 5-minute test there will be three rapid walk-by at 300mm behind the manikin. Each walk-by will be spaced 30 seconds apart. If there is a rise in test gas concentration, it cannot exceed **0.10 ppm** and must return to 0.05 **ppm** within 15 seconds.
- There will be a minimum of three and a maximum of five people in the test room during the test procedure.
- Representatives of the NIH will witness the tests.

<u>Dynamic Testing:</u> These tests primarily test the dynamic performance of the fume hood control system. This group of tests measures hood performance parameters through various dynamic "events". Events shall include four sash movements up and down across differing ranges: 25% - 100% and 50% - 100%, sash movements of other hoods on the exhaust duct, walk-bys in front of the hood, and opening and closing the laboratory door commensurate with a person entering and exiting the room.
Hood parameters to be determined for each event are defined as follows (refer to the figure below for a graphical representation of some parameters):

- **Measured Face Velocity** (FVm expressed in m/s): Face velocity measured in the plane of the sash. Samples shall be recorded at no less than 10 hz. Sensing methodology shall have an internal time coefficient of no more than 20 ms. This shall basically be a point sensor located in the middle of the face opening when the sash is at the lowest position during the tested event. No less than three point sensors shall be used. Averages shall be calculated for any point in time to assess overall measured face velocity, however individual sensor samples shall be used in calculating TI.
- **Total Exhaust Air Flow** (TEFexpressed in L/s): Total exhaust flow measured in the main exhaust duct leaving the hood.

This parameter shall be recorded at no less that 10 Hz. The sensing methodology used for the recorded data shall represent the total airflow through the full range of flows and be validated by independent multi-point measurement. If the fume hood control system uses a flow sensing element, that element may be used assuming it can be calibrated across the full range of flow. Sensing elements must have an internal time coefficient of no more than 20 ms.

- **Variable Face Area** (FAv expressed in meters): Face Area of the hood that varies as the sash is moved within specified limits

- **Fixed Face Area** (FAf expressed in meters): Face area of the hood with sash at minimum position (minimum position should correlate with the minimum bypass flow through the hood)

- **Hood Airflow Leakage** (HAL expressed in L/s): The difference in airflow between the measured airflow through the face (at minimum position) and the total air flow measured in the exhaust duct.

- **Calculated Face Velocity** (FVc): Face velocity determined from the following equation: ((TEF-HAL)*1000)/(FAv + FAf)

- **Steady State Face Velocity** (SSFV): The average of all sampled face velocities for a 5 second period. Two SSFVs will be determined for both measured face velocity and calculated face velocity; one before the event (SSFVb) and one after (SSFVa). The SSFVa will start two seconds after the end of TSS. The second suffix of m for measured and c for calculated shall be used to indicated the type of assessment

- **Face Velocity Baseline** (FVBL): The average of SSFVa and SSFVb

- **Control Linearity** (CL expressed in %): Abs(SSFVa-SSFVb)/(FVBL)*100

- **Time to Steady State** (TSS_{10} and TSS_5 expressed in seconds): The elapsed time from the initial sash movement until the FVc reaches and stays within ± 10% or ± 5% of FVBL (as indicated by the subscript)

- **Face Velocity Overshoot/Maximum Deviation**-(FVO expressed in %): Calculated using the *Calculated Face Velocity* sample furthest from the FVBL (FVf) throughout the test per the following equation: (Abs(FVf-FVBL)/ FVBL)*100. Samples include initial face velocity deviation immediately following the sash movement as the controls initially respond to the movement of the sash.

- **Response Time Constant** (RTC expressed in seconds): Elapsed time between initial movement of the sash and the initial subsequent movement of the exhaust valve.

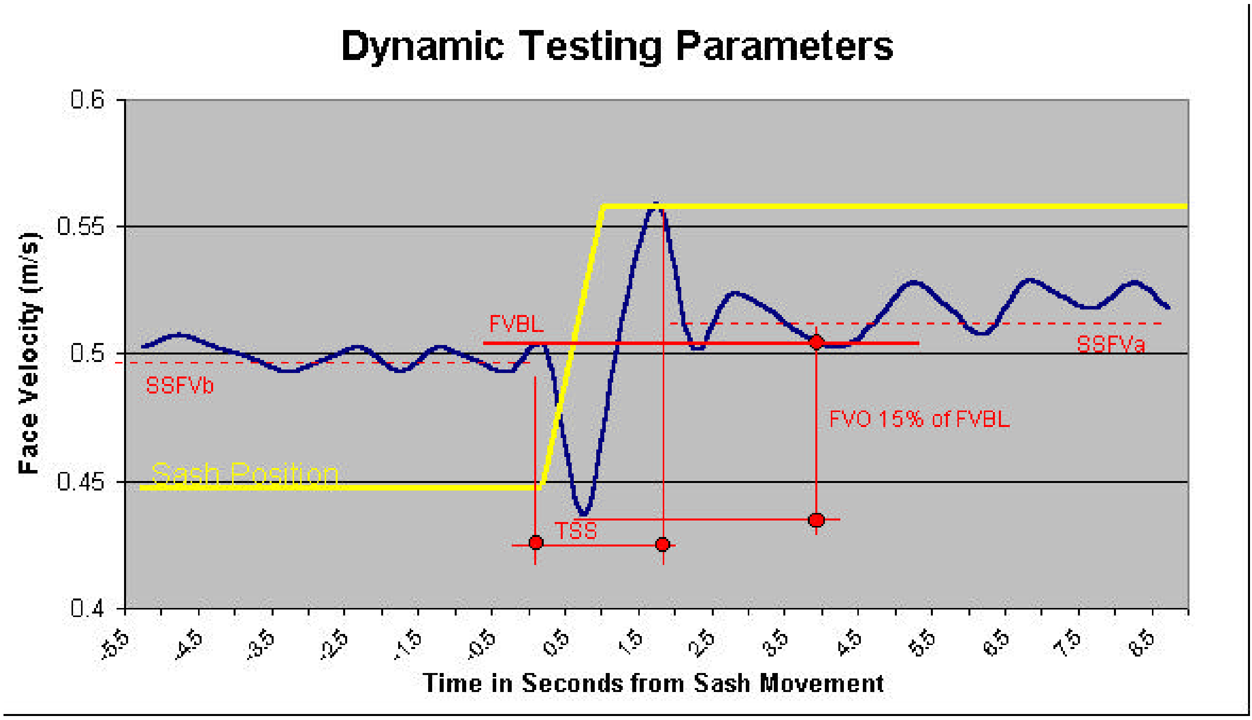
- **Steady State Deviation** (SSD expressed in %): Face velocity variation from SSFVa or SSFVb as applicable. Calculated using the furthest sample from the applicable SSFV (FVf) using the following equation:
  (Abs(FVf-SSFVx)/SSFVx)*100

- **Controllability** (expressed in mV/mm): Describes controller response to changing sash position, ie: Controllers response signal change per unit distance of sash movement

- **Sash Position** (SP expressed in mm): For vertical sashes - Vertical distance from the sill of the hood to the bottom of the sash. The minimum sash position shall correlate to the position of the sash when the minimum flow through the hood is all through the face. Maximum sash position shall be defined as a distance of 550-650mm. This parameter shall be recorded at no less than 10 hz.

- **Controller Output** (CO expressed in Volts): Control output to the controlling exhaust air valve. This parameter shall be measured and recorded at no less than 10 Hz.

- **Turbulence Intensity** (TI expressed in m/s): Calculated root mean square of the fluctuating face velocity determined using FVm. This value shall be calculated for each of the steady state conditions preceding and following each event. This shall be correlated to a "Box Leakage Factor" of the installation using the *Methodology for Optimization of Laboratory Fume Hood Containment"* (MOLHC) by NIH Office of the Director, Farhad Memarzadeh principal investigator. While this value does not have a pass/fail requirement, it is the fundamental indicator of containment and therefore shall be clearly reported.



Parameters Performance Requirements:

Face Velocity Baseline (FVBL): .51 m/s ± .05m/s

Control Linearity (Cl expressed in %): < 2%

Time to Steady State$_{10}$ (TSS$_{10}$ expressed in seconds): < 2 Seconds

Time to Steady State$_5$ (TSS$_5$ expressed in seconds): < 3 Seconds

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

Response Time Constant (RTC expressed in seconds): < 0.5 Seconds

Steady State Deviation (SSD expressed in %): < 5% assessed using calculated face velocities

Controllability (expressed in mV/mm): > 12 mV/25.4mm

Alternate Parameter Performance Requirements:

The following performance parameters are alternate requirements that can be used in assessing acceptable dynamic responses.

Face Velocity Baseline (FVBL): .51 m/s ± .05m/s

Calculated Face Velocity (FVc): All samples >0.255 m/s and <.89 m/s meaning that at no time during the event shall the calculated face velocity go outside that range. Any sample recorded beyond that range will result in assessing the response as unacceptable.

Control Linearity (Cl expressed in %): < 2%

Time to Steady State$_{10}$ (TSS$_{10}$ expressed in seconds): < 1.6 Seconds

Time to Steady State$_{5}$ (TSS$_{5}$ expressed in seconds): < 2 Seconds

Response Time Constant (RTC expressed in seconds): < 0.5 Seconds

Steady State Deviation (SSD expressed in %): < 5% assessed using calculated face velocities

Controllability (expressed in mV/mm): > 12 mV/25.4mm

Test Execution: Testing agency shall be equipped to execute the testing and assess all performance parameters on site the day of the test. Data acquisition of required parameters shall be simultaneous.

Test Documentation: All testing, calculated, and recorded parameters shall be presented in a report that shows the recorded parameters graphically and tabulates and summarizes all the results. Performance of the hood, the hood controls, and the laboratory in general shall be described and summarized.

Note: The following goes only in the control manufacturer's spec.

Fume hood Control Testing (Off Site Mock Up)

The manufacturer of the proposed fume hood control system shall mock up a fume hood installation and demonstrate the performance of their system to validate that they can meet the requirements specified herein. The off site test shall include all parameters under the control of the control system (FVBL, TSS, CL, RTC, SSD, and Controllability). It is not necessary to mock up the installation and assess TI. Events to be tested off site include all specified sash movements on the hood being tested. Walkbys and door opening affects are not required for the off site test.

The testing shall be accomplished by an independent testing agency approved by the A/E and NIH. Reports shall be provided with the laboratory control submittals and no approval will be given for the fume hood control system until documentation of successful demonstration of the performance requirements are submitted.

D.16.24 Machine Room Conditioning

Rooms covered by these guidelines include mechanical, electrical, elevator machine, boiler, autoclave and cage wash equipment spaces. These spaces are typically not air conditioned, but they are heated and ventilated to acceptable levels. Reasonable conditions must be maintained in these rooms for worker comfort, to increase equipment life, and to avoid excessive heat gains and losses to adjacent occupied areas.

Heating for equipment spaces generally consists of steam or hot water unit heaters sized to heat the space to 21^{o}C. Heaters shall be strategically located so they can offset infiltration loads caused by leakage through louvers, ventilation roll-up access doors, etc. Isolated pipes within machine rooms do freeze and break during severe weather conditions and when other systems fail.

All machine rooms shall be ventilated, as a minimum, to code requirements for maintaining acceptable IAQ. Virtually all rooms that house machinery will have internal heat gains that drive ventilation air quantities far above code minimums. Heat gains are generated by motors, transformers, heat exchangers, piping, tanks and vessels, dimmer banks, speed drives, etc. The Project Engineer shall itemize operating equipment and establish estimated heat gains for each space. Radiated heat gains from transformers, steam, and heating systems can be as much as 2% of demand loads. The ventilation systems shall be sized using a -12^{0}C rise above ambient outdoor air conditions. This results in equipment rooms being as high as 40^{0}C in peak summer months.

Secondary Switchgear Rooms shall have HVAC equipment to maintain 24 hours temperature between 18^{0}C and 26^{0}C and humidity maintained at 30% to 60% noncondensing to protect switchgear and electronic controls.

Install temperature and humidity sensors in switchgear/transformer rooms connected to the SCADA system. An alarm printer in the high voltage shop will be programmed to print high and low temperature alarms as well as dew point alarms. This would allow shop personnel to respond to impending problems prior to damping temperatures and moisture.

For large equipment areas with significant air requirements, it is desired to use multiple fans so ventilation can be staged by thermostatic control. When combustion equipment exists within a machine room, the ventilation requirements shall be combined with combustion air load and the space maintained at a positive pressure. Combustion equipment requires forced ventilation whenever operating; therefore freeze protection becomes a more critical issue in winter months. Combustion air is best handled using a heating and ventilating unit to temper the air before distributing to this room.

Elevator machine rooms, telecommunication closets, fire alarm rooms, and other similar spaces with electronic equipment may require air-conditioning instead of ambient ventilation. The Project Engineer should define criteria for these spaces and design accordingly. Many times these rooms require air-conditioning when building systems are off, thereby justifying the use of packaged spot coolers or fan coil units.

The National Elevator Code has specific requirements for ventilating elevator shafts and machine rooms which must be applied to NIH buildings.

It is desirable to filter make-up air for ventilation of all machine rooms, but this becomes impractical due to large air quantities in many cases. Electrical room ventilation should always be filtered with efficiencies of 30% based on ASHRAE's Standard 52-76, atmospheric dust-spot test efficiency.

The National Electrical Code and National Elevator Code strictly prohibit the installation of mechanical systems in those rooms unless they serve the space. When locating heating equipment and routing piping within these areas, care shall be taken to minimize the length of run and not to run over electrical equipment.

D.16.25 Emergency Generators

These guidelines serve as the basic criteria for the application of emergency power generators in NIH buildings. Virtually all buildings on the NIH campus use emergency power to back up life safety systems and supply critical equipment and spaces with power in the event of a normal power outage. Generator installations create numerous problems for the mechanical engineer which must be resolved in the early design stages. Requirements to be considered for installation are as follows:

- A location that is easily accessible for service and future replacement
- A mounting method to avoid structure-borne vibration
- An engine exhaust discharge location
- An engine-cooling system
- Ambient ventilation
- A fuel supply system

The following list of standards, issued by the NFPA, pertain to the installation and operation of generator sets. Installation standards and codes are subject to change and may vary by location or over time. The mechanical engineer has the responsibility for following all applicable local, state, and national codes and regulations.

- NFPA Standard 30 Flammable Liquids Code
- NFPA Standard 37 Combustion Engines
- NFPA Standard 54 National Fuel Gas Code
- NFPA Standard 58 LP-Gas Storage, Use
- NFPA Standard 70 National Electrical Code
- NFPA Standard 99 Health Care Facilities

- NFPA Standard 101 Life Safety Code
- NFPA Standard 110 Emergency and Standby Power Systems

The generator location is determined mainly by related systems such as ventilation, wiring, fuel, and exhaust. The location should be away from high ambient temperatures and protect the generator set from adverse weather conditions. The generator set should be close to the main power-consuming equipment.

The generator room must be large enough to include space for accessories such as batteries, control switchgear, and day tanks. Adequate access to the generator set for service and repair should be planned. At least 1.2 m of clearance should be provided around the generator set. There should be access for replacing the generator without moving the generator set or accessories, such as a day tank.

The location must be such that adequate ventilation can be provided to supply combustion air and remove heat dissipated by the engine, generator, accessories, and radiators. The location must allow the exhaust system to be routed to the out-of-doors. The exhaust system must be terminated at a location where engine exhaust will disperse away from buildings and building air intakes.

Generator sets located outside of buildings must be protected from the weather. Integral weather protective housing is available for many models. When locating a set out-of-doors, the A/E shall consider the risk of power disruption by wind, ice, snow, flooding, lightning, fire, and vandals.

The generator set shall be located where engine, fan, and exhaust noise levels will be acceptable. Generator noise levels are excessive.

Exhaust System: The purpose of the exhaust system is to direct engine exhaust away from the engine and allow it to discharge into the atmosphere. A muffler should be connected into the exhaust system, either inside or outside the generator set enclosure. For maximum efficiency, and to prevent engine damage, the exhaust system shall not create excessive backpressure on the engine. The correct pipe size, connections, and muffler shall be selected to achieve proper operation of the generator.

When exhaust piping runs through a floor, ceiling, attic, or concealed spaces, the exhaust pipes should be installed within a metal, masonry, or other approved chimney.

The generator set exhaust system shall not be connected to an exhaust system serving other equipment. Soot, corrosive condensate, and high exhaust gas temperatures will damage idle equipment served by a common exhaust system.

Generator sets that are installed out-of-doors with integral weather protective housing shall have a mounted critical-grade muffler. The generator set shall be located so engine exhaust will disperse away from buildings and building air intake and will not blacken walls and windows with soot.

Every precaution must be taken to prevent excessive backpressure on the engine. Exhaust piping must comply with the following general safety precautions;

- Exhaust pipes should be steel and be strong enough to withstand the service. Schedule 40 black iron pipe is recommended.
- Exhaust pipes must be freestanding, not supported by the engine or muffler.
- Exhaust pipes must use vibration-proof flexible connector.
- Exhaust pipes must have a clearance to meet local and national codes from combustible materials and terminate outside of the building.
- Exhaust pipes must be guarded to prevent contact with personnel, or severe burns could result.
- Exhaust pipes must be routed to avoid fire detection devices and automatic sprinkler alarm heads.
- Exhaust pipes must be vented to the atmosphere away from building doors, windows, and ventilation intake vent.
- Exhaust pipe routing and size must be designed to limit backpressure on the engine to within manufacture tolerances.

- Exhaust pipes must be pitched downward and away from the generator set in a horizontal run or a condensate trap with a drain installed where a rise in the exhaust system begins.

- A flexible, corrugated stainless steel exhaust tube must be connected to the engine exhaust outlet to take up thermal expansion and generator set movement and vibration.

The mechanical engineer shall select a muffler that will reduce the exhaust noise to an acceptable level. Three types of muffler are commercially available for the following applications:

- Industrial Muffler: Suitable for industrial areas or remote installation where attenuation is not critical, 12 to 18 dB(A) sound reduction

- Residential Muffler: Suitable where some low background noise is always present, 18 to 25 dB(A) sound reduction

- Critical Muffler: Suitable for the areas of hospitals or residential dwellings or where background noise is minimal, 25 to 35 dB(A) sound reduction

Residential or critical-grade mufflers are commonly used at the NIH depending on the location of the generator. The muffler shall be installed as close as possible to the engine. Cool mufflers collect undesirable carbon residues and moisture. Draining and servicing the muffler is usually more convenient if it is installed near the engine.

The muffler and exhaust piping shall be insulated to prevent burns if accidental contact occurs and to reduce heat gains to adjacent spaces.

Engine Cooling: Liquid-cooled engines use a coolant that is pumped through passages in the engine cylinder block, heads, and sometimes through water jackets around the exhaust manifold. The coolant is pumped under pressure throughout the system. As the coolant moves through the engine, it absorbs heat from the engine. The coolant is then cooled by either a radiator or a liquid-to-liquid heat exchanger. The coolant consists of a solution of water and antifreeze suitable for the coldest ambient temperature expected.

Mechanical engineers may consider various methods of heat rejection including the use of factory-mounted radiators, factory-mounted heat exchangers, and remote cooling methods using various sources. The simplest method consisting of the factory-mounted radiator is the preferred choice by the NIH because it reduces maintenance and comes packaged with the generator.

Mounted radiators are installed on the bases of the generator set in front of the engine. A radiator cooling fan draws air over the engine and pushes it through the radiator. This action provides surface cooling of the engine together with cooling of the engine coolant in the radiator. This method of cooling is independent of interruptible utility supplied cooling water.

<u>Ambient Ventilation:</u> A room ventilation system is necessary to remove the heat and fumes dissipated by the engine, generator, accessories, and other equipment in the generator room. The system is also required to provide an adequate supply of clean combustion air.

Ventilation system sizing shall be based on the required air intake, maximum allowable total pressure drop, and type of engine-cooling system employed. Air inlet capacity must be sized to handle the combined flow of combustion and ventilation air.

Normally there is an air inlet and discharge outlet in the room for circulation. Arrangement of these vents is such that air cannot escape without first passing through the immediate area of the generator set. Locating the outlet higher than the inlet allows for convection air-current flow.

Ventilating air inlet and discharge openings must be located or shielded to minimize fan noise and the effects of wind on airflow. If free airflow is inhibited by louvers or screens, the vent areas shall be increased by 25-50%.

Dampers or louvers protect the generator set and equipment room from the outside environment. Their operation of opening and closing should be controlled by the operation of the generator set(s). Dampers must be open when the set is running.

Thermostatic shutters can be used to control airflow to maintain a desirable temperature range. They regulate airflow during operation and close at shutdown. Closing at shutdown is especially important in cold climates. Natural draining of cold air into the outlet duct can lower the ambient temperature below a safe level for all engines, especially diesels.
In cooler climates, a movable or thermostatically controlled discharge damper can be used. This will recirculate radiator discharge air to keep the room warm when the generator set is operating.

The engine-driven fan set draws air forward over the generator and pushes it through the radiator. The radiator shroud has flanges for connecting a duct to carry the air to the out-of-doors. A flexible duct connector must be provided at the radiator to take up generator set movement and vibration.

Airflow through the radiator is usually sufficient for generator room ventilation. Auxiliary ventilation may be necessary if a low room air temperature rise has to be maintained. It is recommended that a maximum -12 ^{0}C room temperature rise be utilized to design the ventilation air system. Certain generators may tolerate ambient conditions above 41 ^{0}C, but the maximum temperature should be limited to improve performance and generator reliability.

Fuel Supply: For continuous safe and satisfactory operation of emergency generators, fuel supply systems must be engineered and installed to industry standards. Generators may use either a liquid fuel or gaseous fuel source as justified by life cycle costing**.**

Liquid-fuel supply tank construction, location, installation, venting, piping, testing, and inspection must comply with applicable codes and NFPA Standards 30 and 37.

The supply tank must hold enough fuel to run the generator for the prescribed number of hours (NFPA 110 Class designation) without refueling. Tank-sizing calculations shall be based on the hourly fuel consumption at full load. Other considerations for tank sizing include the duration of expected power outages vs. the availability of fuel deliveries and the shelf life of the fuel. The shelf life for diesel fuel is 1-1/2 to 2 years.

For emergency power systems, codes might not permit the fuel to be used for any other purpose, or may specify a draw-down level for other equipment that guarantees the fuel supply for emergency power use. It is the NIH's policy not to permit the generator fuel supply to be used for any other purpose.

For multiple-generator set installations, each set or its day tank shall be connected independently to the fuel supply tank. This will prevent any set from starving for fuel when all sets are operating and prevent entrainment of air into the fuel system of idle sets.

Fuel tanks must be installed in accordance with code restrictions. The fuel tank should be as close as possible to the generator set. Because the fuel pump influences the fuel tank location, the fuel pump lift capability should be considered. If the sum of fuel pressure drop and vertical lift exceeds the lift capabilities of the standard fuel pump, the use of an auxiliary fuel pump and day tank is required.

Federal, State, and local codes have extensive requirements covering tanks and fuel piping installation. The Project Engineer shall carefully consider tank specialties, levelometer alarm and monitoring devices, and testing requirements.

When burying fuel lines, compatible metal fuel lines and fittings shall be used to avoid electrolysis. Black steel pipe shall be used for diesel fuel lines.

A flexible section of code-approved tubing shall be used between the engine and fuel supply line to withstand generator set vibration. Diesel-fueled generator sets require a fuel return line. All fuel line and tank fittings must be properly located and airtight to keep air from getting into the fuel lines.

Fuel supply pipes and pumps must be sized to handle a flow rate three times greater than the full-load fuel consumption rate specified by the generator manufacturer. Fuel return pipes may be sized for twice the flow.

Lifting capabilities are reduced by elbows, bends, and long lateral distances in the fuel line. Note that in the descriptions of the various fuel systems using auxiliary fuel pumps, the vertical lift is limited by the capability of the transfer pump. With a large capacity fuel pump, the vertical distance must not exceed 12 m lift. Fuel lifted long heights causes a pressure drop to the point where the fuel boils, produces a vapor, and causes vapor lock.

An electric solenoid shutoff valve in the supply line is always desirable and required for indoor automatic or remote starting installations. The solenoid wires are connected to the battery ignition circuit so the valve will open during operation.

Day tanks shall be as close as practical to the generator set to provide direct fuel connections, at an elevation where the highest fuel level in the tank is lower than the diesel fuel injectors.

Day tanks are fuel transfer tanks that are used when the standard engine fuel pump does not have the capacity to draw the fuel from the supply tank, or the supply tank is overhead and presents problems of high fuel-head pressure for the fuel return. The day tank is vented to the outside when installed indoors.

Diesel engine return-fuel shall be piped to the supply tank rather than the day tank. Otherwise, the influx of warm return fuel will increase the day tank fuel temperature. As fuel temperature increases, fuel density, and consequently engine power, decrease. Return fuel should be piped to an intermediate day tank with float switch. The pump fuel from there to the supply tank.

Gaseous-fuel supply system installations, operation, and maintenance must comply with all applicable codes and NFPA Standards 37, 54 and 58.

For emergency power systems where the risk of interruption of off-site fuel supplies is high, codes might require an alternate on-site fuel supply and provisions for automatic transfer to the alternate fuel.

Types of Gaseous Fuels: The selection of a particular fuel depends on (1) availability, (2) efficiency required, (3) engine application (mobile or stationary), (4) initial cost, and (5) cost of operation.

Natural gas is composed primarily of methane and varying amounts of other dry gases with a heat content of about 37.25 MJ/m^3. It is piped from the source to points of consumption. Localities that are not serviced by natural gas will frequently have a manufactured gas system.

Manufactured gas is not a particularly good fuel for generator sets if efficiency is important. Manufactured gas has a low heat value, and the engine will have to be derated as much as 50%. While gas manufacturing cost is usually higher than for other types of fuels, there are fewer storage problems and ambient temperatures have no effect on supplies.

LP is a commercial mixture of propane and butane. The ratio between the two varies with local temperatures and user requirements. While propane vaporizes at a lower temperature than butane, butane has a higher heat content. Stored and transported under pressure in tanks, LP is a vapor at room temperature. By increasing pressure or lowering temperature, it remains in a liquid state. Liquid and vapor LP are both used as a fuel for generator sets.

Temperature and Pressure: Temperature and pressure are interdependent. If gas temperature is changed, the pressure will change proportionally. Gas at room temperature can be changed to a liquid by compressing it and storing it in a closed container.

A liquid at atmospheric pressure can be changed to a gas by raising the temperature to the liquid's boiling point. Vaporizing LP builds pressure within the container.

Working Pressure: The fuel system components must operate at various working pressures depending on the kind of gas/vapor, size and length of fuel lines, number of generator sets supplied, ambient temperature, etc. Components must have the strength to function properly under the anticipated or calculated maximum working pressures. LP tanks, for example, must have a minimum design pressure of 1724 kPa per NFPA Standard 58-1983.

D.16.26 Steam Systems

The steam requirements for NIH facilities are extensive and include autoclaves, cage wash equipment, kitchen equipment, HVAC systems, domestic water heating, etc. Steam is generated at the

NIH Central Heating Plant in Building 11 and distributed at a pressure of 1138 kPa. Condensate is returned to Building 11 through a series of low-pressure pump return mains and high-pressure drip condensate piping.

Central plant steam is commonly used for most applications at the NIH. Clean steam produced from RO water or by double distillation shall be used for humidification to special animal housing areas in vivarium, transgenic animal housing areas, special patient holding areas (Bone marrow transplant etc.) and autoclaves etc.

The type and method of steam/condensate distribution to NIH buildings shall be thoroughly evaluated with life cycle costing. The use of service tunnels, pipe trenches, and direct burial shall be considered, and insulation alternatives shall be optimized for energy savings.

Where possible, all steam condensate shall be collected and returned to the plant. Flash tanks shall be utilized to reduce pressure, and the resultant flash steam utilized for low-pressure supply where a continuous demand exists. When the resultant flash steam has no established use, it shall be vented to the atmosphere.

Steam and condensate distributions systems shall be sized conservatively with minimal line pressure loss at maximum design load plus allowances for warm-up and future growth. All valves, traps, equipment, and specialties shall be selected and sized for their intended use by the Project Engineer. Sizing considerations shall include warm-up factors and estimated inlet and outlet pressure.

The room in which pressure-reducing valve (PRV) stations, pumps, converters, etc., are located shall be of suitable size to permit safe access for maintenance of equipment. Main steam isolation valves shall be located close to points of egress from mechanical rooms so that in the event of a system failure valves can be easily accessible for operation. Pump motor starters shall be clearly identified and, where practical, shall be mounted on a common panel. If a duplex condensate pump is installed in pit, the starter, disconnect switch, and alternator are to be located outside and adjacent to the pump pit. Locating any serviceable equipment in a confined space should be avoided where possible.

Steam service rooms have excessive radiated heat gains from piping, valves, and receivers. All such equipment shall be insulated to the full extent possible. Ventilation systems shall maintain room -12^{0}C above ambient conditions or 40^{0}C.

The ASHRAE *Handbook for HVAC Systems and Equipment* and the ASME Code contain specific criteria for the design and installation of steam systems and shall be utilized for NIH buildings.

For NIH buildings steam systems and distribution piping are classified as follows:

• Low-pressure steam	97 kPa and below
• Medium pressure steam	103 kPa through 552 kPa
• High pressure steam	558 kPa and above

It is not uncommon in NIH buildings to have two medium-pressure steam systems (276 kPa and 552 kPa).

Steam shall be supplied to the inlet of equipment steam control valves at the pressure indicated below.

• Radiators	34 kPa
• Convectors	34 kPa
• Air heating coils	97 kPa maximum (higher pressures may be used if justified by engineering or economic considerations)
• Unit heaters	207 kPa maximum
• Domestic hot water heaters	552 kPa maximum
• Central humidifiers	97 kPa maximum
• Terminal humidifiers	97 kPa (duct mounted)
• Dietetic equipment	As specified by supplier

• Sterilizers and washers	As specified by supplier
• Heating water convertors	552 kPa maximum

It should be noted that radiators, convectors, air heating coils, and unit heaters are generally supplied with heating water in lieu of steam.

D.16.27 PRV Stations

- PRVs shall be provided at the building steam service entrance as required to support building steam utilization. Two or three stations may be required and typically have the following reduction stages:

    - High to medium: 1138 kPa to 552 kPa
    - Medium to medium: 552 kPa to 276 kPa
    - Medium to low: 552 kPa to 97 kPa

- Secondary or remote PRVs installed out within the building are not desirable. Second-stage PRVs may be installed in mechanical penthouses or other easily accessible mechanical spaces. Small PRVs which serve isolated equipment such as glasswashers with different pressure requirements may be installed close to that equipment in a service corridor or other suitable space. In no case shall high-pressure steam be reduced in a single stage to either 276 kPa or 97 kPa.

- PRV stations shall be sized for the calculated peak demand of building heating, domestic hot water, humidification, and process equipment load. For process equipment load, use 100% steam consumption of the largest single user plus 25% steam consumption of all other users. Station sizing shall include provisions for future growth.

- Where a single PRV would exceed 75 mm in size or the turndown ratio (maximum load/minimum load) is greater than 254 mm, two PRVs shall be provided in parallel, one for approximately 0-33% for low-load conditions and one for 33-100% for high-load conditions, with a single bypass. For large PRVs where valve sizes are exceeding 150 mm, three PRVs shall be provided in parallel, one for approximately 0-33% for low-load and two for 33-100% for high-load conditions with a single bypass.

- Where the steam service includes capacity for future expansion, all PRV station components except the PRVs shall be sized for the future. The PRVs shall be sized for the present load.

- All PRV valves shall be selected, and both the required load and the maximum capacity (for safety valve sizing) shall be scheduled for that valve.

- The PRV bypass valve and the safety valve shall be sized according to National Board Inspection Code of the National Board of Boiler and Pressure Vessel Inspectors (Columbus, Ohio). The safety valve shall be sized to handle the maximum flow of the largest PRV or the bypass. The bypass valve capacity must not exceed the capacity of the safety valve. Bypass valves shall have two isolation valves; the first valve to secure steam and the second to modulate pressure.

- PRV stations and headers shall be fabricated using fully welded fittings; flanged base plates are not acceptable. The high-pressure main shall have a single shutoff valve capable of securing all steam to the building. Every branch of the PRV station shall have a single shutoff valve capable of securing steam without approaching the station.

- PRV stations must be isolated from the structure to limit structure-borne noise. The maximum valve NC level shall not exceed that specified at all anticipated loads. A noise suppressor shall be provided as required. PRVs shall be fitted with custom, fabric insulation jackets to further reduce noises and heat gain to the space.

- Steam valve pilot lines must be sloped down to tie into mains and must be contained within isolation shutoff valves. Pilot lines shall be at least 15 mm to prevent clogging.

D.16.28 Condensate Return Units

- Condensate receivers shall only serve low-pressure mains and the discharge from flash tanks. Receivers shall not be used as flash tanks or have high- or medium-pressure condensate directly piped, regardless of capacity.

- Condensate return units may be either duplex electric or steam powered. Electric pumps shall be centrifugal, 26 rad/s maximum with Viton seals and stainless steel shafts. Each pump shall have isolation valves on both the inlet and discharge lines to accommodate service.

- Each condensate return unit shall be piped with a full-size bypass line to drain. The bypass serves as emergency manual drainage for condensate if the return unit is off line. The bypass shall be indirectly piped to the sanitary system and have a cooling trap to temper condensate down to a suitable temperature prior to discharge.

- All condensate receivers shall be vented outdoors and independent of steam relief vents.

- Condensate return units shall have fully packaged controls, starters, disconnects, and high-level alarms.

D.16.29 Steam Traps

- Steam traps shall be sized for their particular application. The safety factor to use in the selection will depend on the accuracy of the estimated load, estimated pressure at trap, and estimated back pressure. Safety factors based on type of trap and application of trap shall be as follows in Tables No. 12 and 12A.

Table No. 12
Safety Factors for Steam Traps

Type of Steam Trap	Safety Factor
Balanced-Pressure Thermostatic Traps	2 to 4
Thermostatic Traps	1.5 to 2.5
Liquid Expansion Traps	2 to 4
Bimetallic Traps	2 to 3
Float and Thermostatic Traps	1.5 to 2.5
Inverted Bucket Traps	2 to 3
Thermodynamic Traps	1.2 to 2

Table No. 12A

Application	General	With Temperature Control
Mains Drainage	x2	-----
Storage Heaters	x2	-----
Unit Heaters	x2	x3
Air Heating Coils	x2	x4
Submerged Coils (low-level drain)	x2	-----
Submerged Coils (siphon drain)	x3	-----
Rotating Cylinders	x3	-----
Tracing Lines	x2	-----
Platen Presses	x2	-----

Rule of Thumb: Use factor of 2 on everything except Temperature-controlled Air Heater Coils, Converters, and Siphon applications.

- Numerous different steam traps are available, and each may serve a multitude of applications. Table No. 13 lists various trapping applications and provides first and second recommendations for each case.

Table No. 13

Recommendations for Steam Trap Applications

Application	Float/ Thermostatic	Float/ Thermostatic with Steam Lock Release	Float/ Steam Lock Release	Thermo-dynamic	Balanced Pressure Thermostatic	Bimetallic	Liquid Expansion	Inverted Bucket
CANTEEN EQUIPMENT Boiling Pans - Fixed	A	B	B1	B1	B			
Boiling Pans - Tilting		A	B		B			
Boiling Pans Pedestal	B	B	B1		A2			
Steaming Ovens					A2			
Hot Plates	B	B	B1		A2			
FUEL OIL HEATING Bulk Oil Storage Tanks				A				B1
Line Heaters	A							B1
Outflow Heaters	A							B1
Tracer Lines & Jacketed Pipes				B	A3	B	B	
HOSPITAL EQUIPMENT Autoclaves and Sterilizers	B	B	B1		A			
SPACE HEATING EQUIPMENT Shell & Tube Heat Exchangers	A	B	B1					B1
Heating Coils and Unit Heaters	A	B	B1					B1
Radiant Panels and Strips	A	B	B1	B1				B1

Radiators and Convection Cabinet Heaters	B				A	B		
Overhead Pipe Coils	B				A			B
STEAM MAINS Horizontal Runs	B			A	B2			B
Separators	A			B	B2			B
Terminal Ends	B			A1	B2			B1
Shut Down Drain (Frost Protection)					B3		A	

A = First Choice for Application

B=Second Choice for Application

Notes:1.Apply Trap with air vent in parallel

2.Install at end of cooling leg, minimum length 0.91 m

3.Use special tracing traps which offer fixed temperature discharge option.

Reference:Steam trap data was taken from Spirax Sarco Application and Hook-up Data

D.16.30 Piping Systems

Piping shall be designated and installed to allow for expansion and contraction without creating excessive stresses and strain in the system. Expansion loops, offsets, and bonds shall be provided wherever possible. Expansion joints shall be provided as a last resort. Pipe anchors shall be designed for each location and sized to handle all forces with conservative safety factors. All anchors, guide loops, and joints must be readily accessible for maintenance and inspection.

Regardless of steam and condensate pressure classification, all pipe and fittings shall be rated for minimum 136 kg at NIH. Steam piping shall be a minimum Schedule 40 and condensate piping a minimum of Schedule 80. Steam connections to equipment 50 mm and larger must be flanged and threaded for sizes 40 mm and smaller. Flange gaskets and bolts shall be suitable for operating pressures and temperatures of the system. Hardware shall be selected so that temperature and pressure fluctuations in the system and expansion/contraction do not effect performance over time.

Steam mains shall be dripped to accommodate condensate drainage at all locations. Drip connections shall be provided at the base of each low point in mains and just before all equipment connections.

Condensate piping must be gravity drained after steam- consuming devices such as coils, heaters, sterilizers, etc. There shall be a hydraulic head between the trap and coil of 450 mm minimum to ensure drainage. Where the hydraulic head is not achievable, condensate pumps must be utilized. Under no circumstances shall condensate be lifted after a modulating device, and condensate must drain freely by gravity.

High-pressure drip lines on steam distribution mains shall be routed to individual buildings and not connected to pumped return lines to plant. High-pressure and medium-pressure condensate shall be piped independently to individual building's flash tanks before connection to the condensate receiver. Flash tanks shall be factory fabricated and ASME stamped and approved. Contractor shop-fabricated tanks are not acceptable.

Float & thermostatic trap with leak sensor and check valve is the choice of preference at NIH. Traps shall be used as opposed to bucket traps and must be sized for present load with a warm-up factor. Condensate shall not be lifted downstream of float traps. Trap bypass valves shall not be installed; if redundancy is required or capacity dictates, dual traps shall be installed. Thermodynamic steam traps for constant loads and Float and Thermostatic Traps for Intermittent loads may be used as required for the application to design the system with approval from NIH.

All steam relief valves shall be piped individually and discharged 2100 mm. above the building roof. Care shall be taken not to locate discharge's close to outdoor air intake or where they could be a hazard to maintenance personal. Relief valves shall not be connected to other steam vents. All valves, drip pan elbows, and relief lines must meet ASME requirements.

Steam valves and specialties shall be of the industrial high-performance type. Positive shutoff and isolation of mains are critical to the safety of maintenance personal. Stainless steel seats and disk are required. Steam strainers shall be positioned horizontally (flat) to prevent condensate from collecting in the bottom of the strainer and reducing its life.

Steam vacuum breakers, not check valves, shall be used on coils and heat exchangers to eliminate vacuum. Vacuum breakers shall be located external to air handling unit casing. One-third/two-thirds control valves shall be utilized for all heat exchangers and for coils where control is critical or capacity is large.

Steam pressure gauges shall be liquid filled with a range consistent with operating pressure. Stainless steel ball valves shall be used for gauge cocks.

Warm-up valves 20 to 25 mm in size shall be provided on all steam mains.

Steam to lab equipment shall have a drip leg installed before connection to prevent condensate buildup. Condensate must drain by gravity away from lab equipment.

Steam instrumentation sensors require a 600 mm long sensing line from header to sensor to protect it from extensive heat.

Steam control valves shall be fully proportional with modulating equal percentage plug. Steam valves shall be designed to modulate and be sized to meet loads at full and partial loads. All steam control valves shall have stainless steel trim and be suitable for the pressure condition and shall operate with the differential pressure required. All steam valves shall be minimum 1725 kPa.

Steam and condensate piping within NIH buildings shall be sized for the parameters in Table No. 14:

Table No. 14
Parameters for Steam and Condensate Piping

Steam Service	Supply Mains & Risers Maximum Drop kPa *	Supply Mains & Risers Maximum Friction rate kPa/30 M	Return Mains & Risers Maximum Drop kPa *	Return Mains & Risers Maximum Friction Rate kPa/30 M
High-Pressure System	10 %	14-55	10%	14
Medium-Pressure System	5%	14	5%	7
Low-Pressure System	5%		5%	

Note: * - Percentage of supply or return main initial pressure.

D.16.31 Chilled Water Systems

Chilled water shall be provided from the existing NIH central chilled water distribution system. The building chilled water supply design temperature shall be 6°C. The A/E shall select the chilled water heat transfer terminals to ensure that the interior space relative humidity is maintained at full- and part-load conditions with a constant minimum leaving chilled water temperature from the building of 16°C.

Multiple-building (tertiary) chilled water pumps shall be provided including 100% standby capacity. The system primary and secondary pumping are provided at the central plant.

All terminal HVAC coils and equipment shall be provided with two-way control valves. The use of three-way control valves is prohibited. The selection of the terminal heat transfer equipment shall be made in conjunction with the control valve to maintain 16°C leaving water temperature at all part load conditions. Each of the building chilled water pumps shall be variable speed. The speed of the pumps shall be varied from differential pressure across a remote and representative portion of the building's chilled water system.

Special areas such as operating rooms and computer rooms may

have dedicated chilled water pumps installed with a hydraulic bridge. Dedicated or general-use chilled water pumps serving critical areas shall be provided with emergency power.
Turbine or venturi-type water flow measuring devices in main chilled water piping shall be provided.

All valves and accessories will be arranged in a systematic manner in places accessible for maintenance and operation. Access doors shall be provided for valves in concealed spaces. Crossing of construction joints with chilled water pipes shall be avoided.

Chilled water piping within buildings shall be sized for a maximum velocity of 2.4 m/s and a unitary pressure drop of 1.2 m per 30 m of piping.

Chilled water piping from the distribution system to the building shall be sized for a maximum velocity of 0.06 m/s and a unitary pressure drop of 1.2 m per 30 m of piping.

For large facilities with floor areas greater than 9290 gross m^2 consideration shall be given to providing multiple building chilled water services to the structure.

D.16.32 Hydronic Heating Systems

Hydronic heating systems are used for various services in NIH buildings. They may serve preheat coils, reheat coils, perimeter radiation, fan coil units and domestic water heaters. The building size and design criteria often dictate whether all services are supplied by a single system or multiple ones.

Regardless of the equipment served by the system, most hydronic heating systems have similar components and piping arrangements. A typical system consists of a duplex shell and tube convertors, duplex distribution pumps, expansion tank (s), makeup provisions, and two- or three-way terminal device control valves.

Hydronic heating systems normally have main and standby components with 100% capacity in the event that lead components fail. On large systems three sets of convertors and pumps can be provided, two to carry the load and one as standby.

Each shell and tube convertor is supplied with either low- or medium-pressure steam and provided with 1/3 and 2/3 capacity control valves for uniform temperature control. Single control valves may be utilized for low capacity convectors and where close temperature control is not required. Steam mains must always be dripped adjacent to convertor connections to ensure a good-quality steam flow to the convertors. Condensate discharge shall be lifted downstream of convertors unless it is pumped. Single condensate traps are normally provided for each convertor without bypass piping. Where large convertors are installed, the A/E may design duplex traps of 50% capacity each.

The entire hydronic heating system may be provided in a manufactured package depending on its size. Packaged systems are typically skid mounted, prepiped, and wired. The manufactured package must be of sufficient size to accommodate service of all components and replacement of major parts without shutting the entire system off.

The systems may be either constant or variable flow based on the control valve arrangement and design concept. It is desirable to use a variable-flow concept so that the large diversity often found in hydronic heating systems can permit the downsizing of convertors, pumps, and piping to minimize initial cost. Variable flow is easily obtained using VFDs on large systems and differential pressure control on smaller ones.

Hydronic heating water systems designed specifically for preheat coils shall have a minimum 40% glycol solution for freezer protection of coils. One hundred percent outdoor air units shall also have duplex coil circulating pumps to provide a continuously uniform heating water flow across the entire coil face areas. Coil circulating pumps may be either in-line or base mounted and located for easy service. In-line pumps may be located overhead provided that safe service platforms and permanent rigging devices are installed to accommodate replacement of pumps. Inline pumps shall not exceed 5600 W hp in size.

Hydronic heating water systems shall be segregated when different design temperatures are required due to seasonal changes. Those systems which serve reheat coils, perimeter radiation, and fan coil units may have the discharge temperature reset as a function of ambient conditions for improved operating efficiency.

For reheat and miscellaneous heating applications, such as hot water coils (duct mounted, furnished with air terminal unit, fan coil units), unit heaters, radiant panels, cabinet unit heaters, convertors, etc., provide one common heating system. The use of two totally separate and independent heating systems (one for reheat and other for perimeter terminal units) shall be considered only if the use of two systems is proven cost effective by the life cycle cost analysis. With a single, common heating system, care shall be taken to select the lowest hot water temperature reset schedule and to offset the generally constant reheat load of the interior spaces.

Heating elements in building heating systems shall be connected in parallel. Where elements are utilized in conjunction with the cooling system supply, controls shall be included with provision for adjustable dead band to avoid simultaneous heating and cooling, unless relative humidity control is essential, in which case simultaneous cooling and heating may be considered.

Piping for hydronic systems consist of Type K copper or carbon steel piping with threaded fittings for sizes 50 mm and less and Schedule 40 black steel for sizes 65 mm and larger. Heating piping shall be sized per the following criteria:

Copper Pipe: 1.2 m per 30 m maximum head loss

Steel Pipe: 1.2 m per 30 m maximum head loss and 2.4 m/s maximum pipe velocity

Piping for heating water systems is normally extensive and routed to the remote areas of all buildings. During the schematic design phase the Project Engineer shall develop a piping concept that reduces long- and small-sized terminal runs and accommodates easy system balancing to all heating devices. Wherever possible, reverse return piping networks shall be employed as they tend to be self-balancing and force flow to the remote ends of the network.

Each piece of heating equipment shall have a means to balance the water flow, determine through balancing the water flow, and control the heat capacity. Large capacity coils, over 0.63 L/s flow, shall have pipe-mounted flow m fittings. Smaller coils shall have pressure/temperature plugs on the supply and return mains to accommodate balancing.

Primary distribution pumps are always base-mounted, end-suction or split-case, double-suction pumps. Close-coupled pumps are not acceptable. All pumps, coil circulating, and distribution shall have the following components to support maintenance operations:

- Isolation valves on suction and discharge lines
- Pipe strainer or suction diffuser with strainer
- Flexible connections on suction and discharge
- Check valve on discharge
- Balancing valve with memory stop on discharge
- Pressure gauges and thermometers on suction and discharge lines
- Pump inertia base and vibration isolation when not installed slab on grade
- Pump speed shall not exceed 26 rad/s

D.16.33 Secondary Chilled Water/Process Cooling Water Systems

Secondary Chilled Water: Secondary chilled water systems used in NIH buildings serve fan coil units, refrigerant condensers, and other miscellaneous cooling equipment. The operating temperatures of these systems closely follow that of the central chilled water so that secondary equipment efficiency is optimized.

Secondary chilled water is most often generated by the central chilled water through plate and frames heat exchangers. Two heat exchangers of 100% capacity each are always provided so that one can be serviced with the system operational.

The central chilled water system is operational year round but is prone to occasional outages to accommodate maintenance functions and nonconstruction. When the secondary chilled water system serves critical equipment that must remain in operation continuously, the A/E should consider the use of supplemental building chiller to backup the central system. Supplemental chillers may be in direct contact with the secondary loop or be connected through three fluid-plate and frame heat exchangers.

Process Cooling Water: Process cooling water systems used in the NIH buildings serve equipment or research functions that are not related to the building HVAC systems. These systems may have a highly diverse range of operating temperature and pressures that will eventually force the use of multiple systems. The A/E must define in the early design stages the design criteria for all such systems. The Mechanical Engineer should be an active participant in programming meetings.

Process cooling water may be generated by the central chilled water of a building condenser water source depending on the required operating temperatures. Plate and frame heat exchangers are commonly used to segregate the systems. Two heat exchangers of 100% capacity each are always provided so that one can be serviced with the system operational.

Process cooling water systems are extremely critical because of the functions they serve. The system must have two reliable sources to generate the cooling water. When central chilled water is utilized, a supplemental chiller will be employed, and when condenser water is used, domestic water can be the backup. It may also be desirable to connect domestic water to the process side locally adjacent to the equipment for further reliability. Whenever domestic water is employed, it should be measured and charged to the institutes so it is not arbitrarily wasted.

Process equipment such as lasers may have very specific pressure limitations on both the inlet and discharge sides. Local pressure-reducing valves may be required to protect equipment. Other equipment may have extremely high-pressure drops and require the use of local booster pumps.

It is also not uncommon to have local 20-micron filters adjacent to equipment to improve the quality of cooling water before it enters the equipment.

System Design: The systems may be either constant or variable flow based on the control valve arrangement. Variable flow has proven to be highly effective because of the large diversity of loads and ever changing pressure requirements. VFDs for each pump should be considered for improved reliability.

Each independent fluid connected to the systems shall have its own expansion tank and makeup provisions. Supplemental chillers may operate in winter months and therefore will have glycol fill equipment.

The water quality in those systems is extremely important to reduce maintenance and eliminate fouling in research equipment. High-efficiency strainers and local water filters shall be integrated with the design.

Piping for these systems consist primarily of Type L copper for sizes 100mm and less. Schedule 40 galvanized steel may only be used for sizes 125 mm and larger. Piping shall be sized per the following criteria:

- Copper Pipe: 1.2 m per 30 m maximum head loss and 1.8 m is maximum pipe velocity

- Steel Pipe: 1.2 m per 30 m maximum head loss and 2.4 m is maximum pipe velocity

Piping for these systems is normally extensive and routed to the remote areas of all buildings. During the schematic design phase the design engineer shall develop a piping concept that reduces long, small-size terminal runs and accommodates easy system balancing to all equipment. Wherever possible, reverse return piping networks shall be employed, as they tend to be self-balancing and force flow to the remote ends of the network.

Each piece of equipment shall have a means to balance the water flow, determine through balancing the water flow, and control the capacity. Large-capacity equipment, over 0.63 L/s, shall have pipe-mounted flow m fittings. Smaller items shall have pressure/temperature plugs on the supply and return mains to accommodate balancing.

Dual primary distribution pumps are always base-mounted, end-suction or split-case, double-suction pumps. Close-coupled pumps are not acceptable. All pumps, coil circulating and distribution, shall have the following components to support maintenance operations:

- Isolation valves on suction and discharge lines
- Pipe strainer or suction diffuser with strainer
- Flexible connections on suction and discharge
- Check valve on discharge
- Balancing valve with memory stop on discharge
- Pressure gauges and thermometer on suction and discharge lines
- Pump inertia base and vibration isolation when not installed slab on grade
- Pump speed not exceeding 1,750 rpm
- Discharge control valves where required for pump starting or equipment isolation.

D.17 Plumbing Systems

D.17.1 Types of Systems

The plumbing systems at NIH are categorized as domestic potable water plumbing systems and industrial nonpotable water plumbing systems. In addition, there are medical/laboratory gas and vacuum systems, fuel systems, various types of pure water systems, and process water systems. All plumbing systems installed in NIH buildings shall meet the requirements of the WSSC's *Governing the Installation of Plumbing and Gas Fitting Regulations* unless otherwise stated by these guidelines.

Domestic plumbing systems shall consist of potable hot and cold water piping, domestic water heaters, waste and vent piping, stormwater, and other common general use systems. These systems typically serve areas such as toilets, locker rooms, kitchens, laundries, patient rooms, etc. which may be common to all building types.

Industrial plumbing systems shall consist of but not be limited to nonpotable hot and cold water piping, water heaters, acid waste and vent, pure water systems, medical/laboratory gas and vacuum systems, rack- and cage-washing equipment, glassware washing equipment, safety equipment, and process water systems.

Plumbing requirements are often dictated specifically by end users during the design phase and are subject to change because of improving equipment technology and the need to remain state of the art when the construction process is completed. The design engineer must clearly understand the wide range of utility requirements and design the distribution systems to be flexible and support future connections.

Plumbing systems shall support the needs of the building occupants, be easily maintained and operated, have reliable and redundant components, and be efficient to operate. These systems shall not impose harm on user equipment because of excessive pressures, improper water temperature, or inadequate drainage facilities. Contained pieces of equipment have numerous piping connections which must be concisely detailed and engineered on the contract documents.

Functional Design Considerations: Special consideration shall be given to the design concepts discussed below in order to provide long-term capability, flexibility, and maintainability.

- Overall, the piping distribution should be designed based on a modular layout, even though this arrangement sometimes limits the configuration and locating of individual spaces.

- Piping distribution systems shall consist of vertical risers located in chases, horizontal mains, and individual room runouts to accommodate the architectural layout of the building. In general, the NIH uses a utility corridor concept, a corridor utility shaft concept, or an external utility shaft concept. The design approach should result in a repetitive and standardized grid arrangement of the risers, mains, branches, and runouts. Piping and valving arrangements shall allow for shutdown of individual laboratories, floors, and zones of the system without affecting adjacent areas for modifications and maintenance to the systems. The primary goal for vertical distribution systems is to minimize floor penetrations in laboratory areas.

- Ideally, piped services, except waste and vent systems, shall be distributed in a double-ended horizontal loop which may be sectionalized for alterations and repair. A utility corridor concept, either interior or exterior, shall be utilized with vertical risers feeding horizontal loops.

- Isolation valves shall be provided to accommodate maintenance at each module, group of toilet rooms, program suite, or other branches where routine service will be required. All isolation valves shall be accessible and located on the floor being served.

- Horizontal distribution mains shall be located on the floor of the equipment or fixtures to be served. It is not desirable to upfeed through a floor slab to fixtures above unless absolutely required by rough-in location.

- Adequate space shall be provided for accessibility to permit modifications and maintenance to the system. Service pipe runouts placed at regular intervals in service shafts or utility corridors will ensure maximum accessibility for future connections with a minimum of disruption to research programs in adjacent spaces. Runouts shall be valved and capped if they are accessible and capped without a valve if they are concealed.

- All equipment which must be serviced, operated, or maintained, shall be located in fully accessible positions. Equipment shall include, but not be limited to, valves, cleanouts, motors, controllers, dampers, drain points, etc. Where required, 1.9 mm steel access panels shall be provided. Doors installed in fire-rated walls or shafts shall be labeled and shall match the rating of the construction. Doors shall be of sufficient size to allow access to all components; minimum size shall be 300 mm by 400 mm. Doors in toilet rooms shall be Type 304 stainless steel or have a chrome-plated finish.

- Pipe sizing shall be designed on calculated flow rates, acceptable diversity factors, and reasonable allowable pressure drops for the various types of systems. Where there are architectural and structural allowances for building additions, pipe sizes shall be increased to allow for building expansion.

- Piping material shall be selected on the basis of system pressures, temperatures, and the type of medium flowing to withstand corrosion and erosion.

- All plumbing piping systems must be identified using pipe labels as required by Section D10 Systems Identification. Difficulty in identifying individual pipelines creates serious potential for cross contamination.

- Proper assessment of required water resources and quality is essential for NIH buildings. The quality of water required (distilled, deionized, or treated by reverse osmosis with deionizers) needs to be determined so that the proper selection of water treatment equipment can be made.

- Backflow protection must be provided to protect domestic potable water systems from industrial nonpotable systems and miscellaneous equipment.

- Plumbing fixtures and trim shall be carefully selected to meet the requirements of building users. Fixtures shall be of the low-consumption type as defined by WSSC and have flow restrictors as required. Elbow, knee, foot, and automatically activated faucets shall be provided as dictated by program requirements.

- Submicron HEPA filters between vacuum traps and fixtures valves shall be provided to eliminate microorganisms in hazardous areas such as BL3 or BL4 labs.

- Electric water coolers shall be specified to use chlorofluorocarbon(CFC) free refrigerants and be completely assembled without the use of lead solder.

- All piping systems designed for NIH buildings should be specified with a joint method prohibiting the use of lead solder.

- Building-wide water softeners or treatment equipment is generally not required for NIH buildings because of the good water quality from WSSC's distribution network. Program requirements suggesting the use of such equipment shall be seriously challenged by the A/E and justified in the early design stages.

Fixtures and Trim: Those items will be selected which aid in maintenance of the aseptic environment. Fixtures will be made of nonabsorptive, acid-resistant materials. Lavatory centersets, except in general public areas, nurseries, and scrub areas, will be fitted with wrist blade handles. Sinks in nurseries will have retractable, foot-operated valves while those in scrub areas will have either foot operated valves that pivot upward for cleaning or knee-operated valves. Clinical sinks will have an integral trap in which the upper portion of the water surface provides a visible trap seal. Showers, lavatories, and sinks except service sinks will be equipped with devices to limit maximum flow. Nonslip walking surfaces shall be provided in showers and tubs.

Fixtures, where required, shall meet the requirements of the Uniform Federal Accessibility Standards. Insulating trap kits shall be provided on all lavatories.

Items will be selected which aid in the maintenance of the aseptic environment. Fixtures will be made of nonabsorptive, noncorrosive material.

Items of equipment serviced by utility lines (air, gas, water, and the like) shall be suitably valved so each piece of equipment can be isolated without interruption of services to any other equipment.

Thermostatic mixing valves should be provided for hydrotherapy baths, X-ray processors, and other fixtures requiring controlled-temperature water supplies, if a valve is not supplied by the equipment manufacturer.

Fixtures, devices, and equipment (autopsy tables and the like) must be installed to ensure no crossconnection between potable and nonpotable water supplies.

Shower walls and floors will be constructed of ceramic tile installed on a mortar bed. A maximum 15 mm lip will be permitted on showers. Temperature-regulating mixing valves with a pressure-balancing and flow control device shall be provided for all showers.

All water closets and urinals shall be wall mounted. Water closets shall be of low consumption (less than 6 L per flush). Urinals shall use a maximum of 4 L per flush.

Specifically designed and manufactured carriers shall be provided for all wall-mounted fixtures. Pipe chases shall be sized to accommodate carriers.

D.17.2 Water Supply Systems

The NIH obtains water from WSSC. The water is supplied through an underground grid network to the buildings. The water mains into the buildings serve the domestic potable water, the industrial nonpotable water, and the fire protection water system.

The A/E shall determine the adequacy of the water pressure for the areas being designed and provide a triplex water-pumping system to meet water pressures required by WSSC for maximum flow conditions. Minimum water pressure of 276 KPa at the highest outlet shall be provided. Triplex booster systems shall be sized to have at least one redundant or standby pump at peak load. Pump sizing shall be optimized to consider low- and high-flow conditions. The use of an accumulator tank may be evaluated.

A pressure-reducing valve assembly shall be provided if required to limit the maximum water pressure to 552 KPa at any service outlet.

Water pressure shall be based on fire flow test data taken from the closet hydrant during the design phase. Dated flow tests are not acceptable.

The A/E shall design the water distribution system in such a way that domestic potable water is protected from backpressure and backsiphonage (the flow of water or other liquids into the distribution pipes from any other source(s) other than its intended source) from the industrial nonpotable and sprinkler water system(s), by proper application of backflow preventers. Backflow preventers shall be installed in accordance with policy guidelines for backflow protection. See Section 17.9 Backflow Prevention(BFP).

In the early design stages a water supply distribution approach shall be developed that meets all program requirements of the facility. Consideration should be given to the use of three different distribution systems to service domestic potable, industrial nonpotable, and mechanical systems. Laboratory reverse osmosis (RO) water system with local polishing equipment is frequently a fourth system and will be discussed hereinafter. Fire protection systems shall always be isolated from all other water systems. Comprehensive life cycle costing which includes the installed and maintenance cost of backflow prevention devices shall be performed to justify the design approach taken.

The three-system distribution approach has the items in Table No.15 connected to each system:

Table No. 15
Three-System Distribution Approach

Domestic Potable Water	Industrial Nonpotable Water	Mechanical Systems
Toilet Rooms	Lab/Process Sinks	Mechanical Equipment
Shower Facilities	Eyewashes/Drench Showers	Autoclaves
Kitchen/Pantry	Fume Hoods	Hose Bibbs
Water Coolers	Biosafety Cabinets	Process Cooling Water
Animal Drinking Water (w/BFP)	Autoclaves	Wall Hydrants
Janitor Sinks	User Equipment	
Service Sinks	Cage/Rack Washer	
Patient Rooms	Glassware Washers	
Treatment Areas	Hose Stations	
Laundry Equipment	Animal Drinking Water (w/BFP)	

Hospitals will have a minimum of two water service mains, each designed for full capacity (serving potable, process, and fire protection systems) and entering the building at a different location.

All laboratory water fittings shall be equipped with vacuum breakers, in addition to a backflow preventer installed on main.

Smaller building projects, general use facilities, and renovation projects may not require the three-system distribution approach and shall be designed accordingly.

Pipe Sizing: Water piping systems shall be designed for minimal pressure drop and low-velocity to limit noise generation. Pipe mains shall be designed for the maximum calculated flow at the design stage plus 20% for future expansion. Cold water systems shall be sized using flush valve curves, and hot water systems, using flush tank curves. Equipment branches and mains shall be sized based on actual flow requirements without diversity. No building water main service shall be less than 200 mm.

Water pipe sizing shall generally conform to the following parameters:

- Copper Cold Water Pipe - 2.4 m/s and 2.4 m per 30 m head loss maximum
- Copper Hot Water Pipe - 1.8 m/s and 2.4 m per 30 m head loss maximum
- Galvanized Steel Pipe - 3 m/s and 3.6 m per 30 m head loss maximum

The allowable number of 25 mm inch flush valves served by various sizes of water pipe shall be as follows:

Pipe Size	No. 25 mm Flush Valves
25 mm	1
32 mm	2
40 mm	3-4
50 mm	5-12
65 mm	13-25
80 mm	25-40
100 mm	41-100

Domestic Potable Cold Water (CW): Domestic CW shall be connected to all general-use-type fixtures. Shock absorbers should be considered for use where flush valves, solenoid valves, or other quick-closing devices occur to prevent water hammer. Shock absorbers shall be supplied at every bank of fixture containing three or more flush valves. Shock absorbers when installed shall comply with PDI WH201 or ASSE 1010. When installed, shock absorbers must be accessible for maintenance. Domestic CW supplies drinking water, food processes, ice machines, etc. which are intended for human consumption and therefore must be protected from backflow from other systems in strict compliance with code requirements.

Domestic Potable Hot Water (HW): Domestic HW is generated from a domestic CW source using steam heat exchangers in most cases. Packaged electric- or gas-fired heaters may be employed for small applications. HW is heated to a temperature of 60 ^{0}C for utility fixtures and tempered down to 43 ^{0}C for distribution to general use fixtures. Kitchens will require HW to be either boosted locally or generated to 82 ^{0}C for dishwashing.

A thermostatic mixing valve shall be used to achieve the 43^{0}C distribution temperature. Program requirements may dictate the use of high-temperature alarms and safety shut-off devices to protect building occupants from excessive hot water temperatures. Pressure-balance thermostatic mixing valves shall be utilized at all showers. All mixing valves shall have integral check stops to prevent crossover of either hot or cold water.

Domestic Potable Hot Water Recirculating (HWR): Recirculating systems shall be designed specifically for each application to maintain the required HW system temperature. The recirculation rate shall be sufficient to offset system heat losses and adequately cover all pipe runs. Reverse return piping layouts yield better results and are easier to balance. Each recirculating balancing valve shall have adequate flow to control, at least 0.06 L/s with 15 mm pipe size.

Industrial Nonpotable Water (ICW, IHW, IHWR): System features may be similar in many respects to the domestic systems, but the two must be totally isolated. All laboratory, vivarium, and process equipment and fixtures shall be connected to the industrial water system. Separate cold, hot, and recirculating water mains and water heaters, tempering valves, etc. shall be provided.

Industrial water system sizing is driven by user requirements which are normally difficult to define. The A/E shall establish through extensive consultation with researchers the design criteria for each type of space so that the utility services are delivered in sufficient quantity and pressure to meet current and future requirements. Design criteria shall be documented and approved early in the design stages.

Mechanical Water: The mechanical water system is limited to a CW source that provides makeup for building HVAC systems, backup for cooling water systems, routing maintenance cleaning, and watering.

Sizing is based on initial or quick-fill requirements and design flows for backup conditions.

Hose bibs shall be provided within the building equipment room for cleaning and within planters for watering. Wall or yard hydrants shall be provided outside the building to accommodate landscape watering, pavement/sidewalk cleaning, and loading dock cleanup.

D.17.3 Sanitary and Waste System

Sanitary, waste, and vent systems shall meet the requirements of WSSC. Each plumbing fixture or drain shall be trapped and vented in accordance with code requirements. The sizing and pitch of drainage piping shall be per code.

For general applications, drain piping can be hubless cast iron or polypropylene plastic pipe. For laboratories intended for research in biology and chemistry, or other research where concentrated acids may be accidentally or improperly discharged into the sanitary drain system, or for laboratories and cage wash facilities in which acids will be used, acid-resisting piping and vent material shall be considered in consultation with the NIH Division of Safety and the Maintenance Engineer. These drain systems shall empty in neutralization and dilution tanks prior to their discharge into the public sewer. The neutralization and dilution system shall be adequate to provide the proper pH discharge into the system. Vent piping material shall be the same as the drain lines.

Laboratory acid, vivarium, or other special waste and vent systems shall be separate from the general use sanitary system.

The effluent from the buildings shall meet WSSC requirements. Effluent with the following basic characteristics shall be excluded from the sanitary sewer system:

- Unmetered water such as air-conditioning condensate, stormwater, ground water, etc. except as allowed per the code

- Any liquid or vapor having a temperature higher than 60 ^{0}C

- Any water or waste containing grease or oil or other substance that will solidify or become viscous at temperatures between 0 ^{0}C and 60 ^{0}C

- Any waters or wastes having a pH lower than 5.5 or higher than 9.0, or having any other corrosive property capable of causing damage or hazard to structures, equipment, or personnel of the interceptor, other sewage-handling and transporting facilities, or other treatment works

The public and private on-site sanitary sewer systems shall be protected against the potential discharge of grease and oil originating from food-handling and related establishments.

Cup sinks, floor drains, and other commonly used drainage facilities are typically installed in a standard manner throughout many NIH buildings without having a specific need or function. The installation of these devices creates a tremendous maintenance problem in maintaining trap seals. The design engineer shall carefully evaluate the need for all such devices and make sure there is a legitimate requirement for their installation. Installing devices in a generic fashion is not acceptable.

Photoprocessing equipment shall be provided with approved silver recovery and waste neutralization tanks adjacent to the equipment. Such equipment is sometimes provided by the users but must be fully integrated into the design.

Drainage lines from kitchens, animal holding facilities, equipment rooms, laundries, and other areas which generate a lot of debris shall be pitched a minimum of 2 cm/m and desirably 4 cm/m. These lines must have adequate cleanout to facilitate rodding, and cleanouts must occur at each 90^0 change in direction.

Condensate drain lines shall also be sloped a minimum of 2 cm/m and shall be minimum 20 mm in size. Cleanouts shall be installed at each 1.6 radians change in direction. Trap seals shall be equal to air-handling unit static pressure at the trap plus a minimum of 50 mm. Condensate line shall be sized per the following table:

Pipe Size (in.)	Maximum Cooling Load (Watts)
20	7,034
25	17,584
32	105,506
40	175,843
50	597,865
80	1,055,055

100	1,512,247

A horizontal distance of at least 1.5 m shall be maintained between parallel underground drains and water lines.

Building sanitary drain connections shall be limited to not less than 100 mm diameter within the building and 150 mm exiting the building.

Building sanitary drain slopes shall provide a minimum velocity of 0.6 m/s. Below-grade piping shall have a minimum slope of 20 mm nominal 2% slope. Above-grade piping shall have a minimum scope of 10 mm/m, nominal 1% slope.

If a grease trap is required by the local authority, sufficient capacity shall be provided to assure cleaning will not be required more than once a month, and traps shall be located external to the building.

Floor drains as a minimum are required in the following areas:

- Kitchen areas, including serving lines
- Mechanical equipment rooms
- Toilet rooms with two or more water closets
- Shower or tub room
- Janitor closets
- Service corridors
- Laundry rooms

Garbage-grinding disposers or pulpers will be provided in kitchens or dishwashers, pot and pan sinks, and other sinks as required. Discharge from garbage grinders will not be piped to grease interceptors.

Floor Drains in Animal Rooms: Floor drains shall be provided in animal rooms only when specifically required by the *Guide for Care and Use of Laboratory Animals.* In addition:

- Floor drains shall be a minimum of 200 mm in diameter, be equipped with a 100 mm water seal trap and cleanout, and have lockable bronze drain covers.

- Deep seal traps and running traps shall not be used.
- Cleanouts shall be provided in the main drain line for proper maintenance.

Floor drains may not be essential in all animal rooms, particularly those housing rodents. Floors in such rooms can be maintained satisfactorily by wet vacuuming or mopping with appropriate disinfectants or cleaning compounds. If floor drains are used, the floor should be sloped and drain traps kept filled with water. To prevent high humidity, drainage must be adequate to allow rapid removal of water and drying of surfaces. Drainpipes should be at least 100 mm in diam. The recommended minimum pitch of sloped floors is 20 mm/m. In heavy use areas, such as dog kennels, rim flush drains at least 150 mm in diam are recommended. A flush drain or heavy-duty disposal unit set in the floor is not a satisfactory solution. A porous trap bucket in the drain can be used to screen out solid waste. All drain pipes should have short runs to the main drains, and if not in use they should be capped and sealed to prevent backflow of sewer gases and other contaminants. Lockable drain covers are advisable for preventing the use of the drains for disposal of materials that should be cleaned up and removed by other means.

When flushing drains or flush devices are employed on drains, access to components shall be maintained. Access becomes a major issue when slabs are on grade or when multiple animal rooms are stacked above one another.

Drain types shall be reviewed with users for suitability in individual rooms. The grate design and strainer elements shall provide adequate rodent and insect protection without increasing maintenance on drains or causing frequent blockage.

<u>Hospital Waste System</u>: The system design for, but not limited to, interceptors, flush-rim drains, and garbage grinders will be in accordance with special requirements for health care facilities.

Interceptors will be provided when substances harmful or hazardous to the building drainage system, public server, or public sewage treatment plant are present in the waste, such as in cast rooms, radiology barium procedure, and blood analyzers. The interceptors will be cast iron; barium interceptors will be aluminum.

Flush-rim floor drains will be provided in autopsy and similar areas.

Floor drains are required in the following areas:

- Autopsy
- Cystoscopy room at front of table
- Hydrotherapy areas
- The vicinity of large refrigerators (such as in blood banks) not equipped with evaporators
- Darkrooms (radiology) for equipment
- Sterilizer closets
- Cart wash
- Ambulance garage/shelter
- Ice machines

A separate drainage and vent system shall be provided for both acid waste and nuclear waste systems. Vents shall be routed through the roof and not connect to each other or the sanitary vent system.

D.17.4 Storm Drainage

A separate drainage system shall be provided for stormwater. The building storm drain shall extend to a distance of 1.5 m outside of the building and connect to the campus storm sewer system. Guidelines for storm sewer systems are included in Section G, Site/Civil.

The number of sizes of drains shall be adequate to convey stormwater from areas being drained at the same rate as water is collected in those areas. At least two drainage points shall be established for each roof or areaway drainage area.

The size of the building storm drain and its horizontal branches shall be based upon the maximum projected area to be drained as defined by WSSC.

System shall be designed on a 81 mm/hour rainfall rate.

Building storm drain slopes shall provide a minimum velocity of 0.9 m/s. The maximum design velocity shall be in the nonerosive range of specified pipe material.

Building storm drain connections shall be not less than 100 mm in diameter within the building and 150 mm exiting the building.

Subsoil drainage is not a plumbing item and shall be indicated on architectural and civil drawings. However, piping design from the low point of the subsoil drainage system to the stormwater building drain shall be shown on the plumbing drawings. Outside building subsoil drain tile shall not be drained to an interior sump pump. If a pump is required, it shall be located outside of the building. Areaway drains, rain leaders, downspouts, or other above-ground drainage points shall not be connected to subsoil drains.

A horizontal distance of at least 1.5 m shall be maintained between parallel underground drain and water lines.

When stormwater vents are required, they shall be piped independently of any sanitary vents.

The waste discharge chart in Table No.16 shall be used to determine where various services are piped.

Table No. 16
Waste Discharge Chart

Type of Discharge	Storm Drain Discharge	Sanitary Drain Discharge
Air Conditioners: Water cooled	X	X
Air Compressors: Water cooled	X	X
Area Well	X	
Bearing Cooling Water: Reclaimed water on individual determination	X	X
Bearing Cooling Water: Reclaimed water if chemical treated		X
Boiler Blow-Down Basin		X
Car Wash Facilities		X
Condensation Drains: Air-handling unit, cooler coil, refrigerated equipment	X	
Cooling Tower: Untreated	X	X
Cooling Tower: If treated, type of treatment chromates		X
Cooling water: Industrial noncontact	X	X
Dies, Tools, etc.: Water cooled	X	X
Drinking Fountain: Nonrefrigerated		X
Drinking Fountain: Refrigerated, water cooled		X
Elevator Pit Drain: Except hydraulically operated elevators		X
Fire System Blow-Down: Automatic, if no additives are applied		X
Food Display Case: Refrigerated		X
Grass Areas	X	
Humidifiers: Commercial	X	X
Humidifiers: Residential	X	X
Ice Machine Drain: Commercial, Industrial	X	X
Ice Chest Drain: Ice Cube	X	X
Loading Docks: Enclosed	X	X
Overflow from Ponds: Ornamented, utility, check for chemical treatment if any	X	X

Overflow from tanks and reservoirs: Private water supply cistern, stock watering and industrial processing, if treated	X	X
Overflow from Tanks & Reservoirs: Industrial process, if treated		X
Roof Drainage	X	
Subsoil Drainage	X	
Water Softener Backwash: Commercial, industrial, & residential	X	X
Welding Equipment: Water cooled	X	X

Notes:

The table may be used for discharge requirements for storm and sanitary waste.

Design must include air gaps as necessary to prevent cross connection between sanitary/storm systems and the water system.

D.17.5 Laboratory Safety Equipment

All laboratory safety equipment shall meet the requirements of ANSI Standard Z 358.1. Safety equipment may have a local alarm indication, but control monitoring is not required.

A laboratory emergency shower piping system shall be provided so that a safety shower can be installed in each laboratory and at other locations deemed necessary by the NIH Division of Safety.

The emergency shower piping system shall consist of a nonpotable water main installed at the ceiling of corridors with a minimum 25 mm diameter branchline from the main to each laboratory on one or both sides of the corridor. A minimum 25 mm horizontal runout shall pierce the wall above the doorway at every laboratory, and an approved emergency shower shall be provided. At locations where an emergency shower shall be installed in the future, the pipe end shall be capped. Branch lines leading to showers shall be installed without shutoff valves.

The showerhead shall be of the on-off type with valves of continued operation upon initial activation. When an emergency shower is activated, the valve shall remain open until manually turned off.

For BL-2 laboratories, emergency showers may be required based on specific program requirements for fume hoods or biosafety cabinets. When showers are required., they may be located within the laboratory or in the pedestrian corridor adjacent to the laboratory. When showers are located within the laboratory they shall be located above the egress door leading to the pedestrian corridor and away from desks and equipment. When they are located in the corridor, they must be within a 10 seconds reach by the lab occupants.

When a BL-3 suite contains a fume hood, an emergency shower must be provided within the containment area of the suite, preferably within the anti-room area. When a BL-3 suite does not contain a fume hood, the emergency shower must be within a 10 seconds reach of the lab occupants. In this case, the emergency shower can be located within the containment area or in the corridor adjacent to the laboratory, provided it can be reached within 10 seconds by the lab occupants.

Where demineralization systems require local regeneration, “safety” showers and an eyewash station should be provided in the area.

Ground fault protection shall be provided for all electrical outlets adjacent to emergency showers as required by the National Electrical Code.

Emergency shower and eyewash stations shall be located on the dirty side of cage wash facilities, and within medical/pathological waste areas, hazardous material storage rooms, and chemical storage rooms.

Eyewash facilities shall be provided in at least one sink in each laboratory, as well as in other areas where chemicals may be used, or as recommended by the NIH Division of Safety. Eyewash units shall be a fixed type, capable of irrigating both eyes at the same time. Upon actuation, the eyewash shall stay in the on position until manually deactivated. Eyewash facilities shall be installed with pressure regulators as recommended by the Division of Safety to prevent injury due to water pressure.

Hand-held drench hoses may be used integral with lab sinks but are not considered as a substitute for ANSI-approved and -required equipment.

D.17.6 Compressed Gas Systems

Medical Gas Systems: Medical gas systems may consist of a cylinder supply system without a reserve supply or a bulk supply system with a reserve supply. Systems will consist of a primary source and a secondary supply that will operate automatically to supply the pipeline if the primary supply becomes exhausted. The secondary supply will consist of at least 3 days' average supply unless the local resupply situation dictates a greater secondary supply amount.

Master alarm panels to monitor line pressures and the status of supply equipment shall be provided. Monitoring shall be done via pressure switches or contacts located downstream of the manifold. Two master alarm panels shall be provided for each medical gas supply system, wired in parallel to a single sensor for each condition. Audible and noncancellable visual signals shall be provided for main-line pressures and for changeover status of manifold systems. Master alarm panels shall be placed in two separate locations: the office or work area of the individual responsible for maintenance of the system, and at a second location monitored 24 hours per day such as a telephone switchboard or security office.

All systems shall comply with the latest edition of NFPA Standard 99.

Bulk systems over 566,340 L shall comply with the latest edition of NFPA Standard 50.

Animal care facilities shall be served by medical gas systems.

All medical gas systems and alarms shall be serviced by the Life Safety Branch of the emergency power system.

Testing and certification of medical gas systems shall be independent of the construction contract and be performed by an agency trained in such services.

Table No. 17 depicts the outlet requirements for hospital gas systems. The piped systems will be sized so that at maximum demand the gas pressure at the outlet is not less than 34 kPa below the normal design pressure. Minimum pipe size for any service shall be 15 mm. Consideration will be given to higher-than-use pressure distribution pressures with local reduction in the alarmed valve boxes for oxygen and medical air in facilities with long piping runs. The gas systems in Table No. 17 will be considered.

Table No. 17
Medical Gas Terminal Outlet Requirements

FUNCTIONAL AREA	OX (1)	MV (1)	MA (1)	NO (1)	N (1)	DA (1)	OE (1)	PA (1)	NOTES
INPATIENT BEDROOMS									
Private Rooms	1	1	1						(2)
Isolation Rooms	1	2	1						
Semiprivate Rooms	1	1	1						(3)
Pediatric Rooms	1	1	1						(3)
Stepdown Rooms	1	2	1						
Day Hospital	1	1	1						
INTENSIVE CARE ROOMS									
ICU Rooms	2	4	2						(6)
SURGICAL SUITE									
Operating Rooms	4	7	2	2	2				(4)(5)
Patient Prep/Holding	1	1	1						(6)
Anesthesia Work Area	1	1	1	1					(4)
Induction Room	1	1	1	1					(4)(6)

RECOVERY									
Intensive Care Recovery	2	4	2						(6)
General Recovery	1	3	1						(6)
Outpatient (Ambulatory) Recovery	1	1	1						(6)
Cardiac Catheterization	1	3	1	1					(6)(4)
Angiography	1	3	1	1					(4)
Cystoscopy/IVP Room	1	3	1	1					(4)
Endoscopy Room	1	3	1	1					
Protoscopy Room	1	3	1	1					
Fracture/Cast Room	1	2	1	1	1				
EEG	1	1							
EKG	1	1							
Treadmill Room	1	1							
Deep Therapy Linear Accelerator	1	1							
Deep Therapy Cobalt 60	1	1							
Computerized Tomo	1	1							
TREATMENT ROOM									
Nursing Station Treatment/ Exam Rooms	1	1	1						
ICU Treatment/Exam Room	2	4	1						
Clinic Treatment Rooms	1	1							
Clinic Recovery Rooms	1	1	1						(9)
EENT Exam	1	1							
ALLERGY/IMMUNIZATION Treatment Room	1	1							
INHALATION THERAPY									
Therapy Cubicle	1	1	1						
Equipment Cleanup		1	1					1	(6)(8)
Equipment Assembly	1	1	1						
PHYSICAL THERAPY									
Hydro Therapy-Extremity	1	1							
Hydro Therapy-Lowboy	1	1	1						
Rehabilitation	1	1							
PHARMACY									
Compounding								1	
CENTRAL MATERIAL SERVICE									
Equipment Cleanup Testing	1	1	1						(7)

BIOMEDICAL EQUIP MENT REPAIR Equipment Testing	1	1	1		1				(7)
NUCLEAR MEDICINE Scanning	1	1	1						
PATHOLOGY Autopsy	1								(10)
DENTAL Dental Treatment									
Rooms (DTRs General)						1	1		(4)(11)
Endodontic DTRs						1	1		(11)
Oral Surgery DTRs	1	1		1	1	1	1		(4)(11)
Recovery	1	1							(12)

Notes:

1. OX=345 kPa Oxygen
MV =Medical Vacuum, 475-625 mm Hg
MA =Medical air 345 kPa oil free air with a dew point of 4 0C
NO =345 kPa Nitrous Oxide
N =1103 kPa Nitrogen
DA=Dental air, 586 kPa oil-free air with a relative humidity less than 40%
OE=Oral evacuation 7 L/s per station at 2,762 kg/m2 of mercury
PA=Process air, nonoil free air at 49 kPa

2.Exclude Psychiatry Unit Rooms.
3. One Medical Air terminal unit per two beds where beds share a common wall, one oxygen and one medical vacuum unit per bed.
4. All inhalation anesthesia anesthetizing locations in a hospital will have an anesthesia gas evacuation system. DTRs with central oral evacuation systems may use the oral evacuation systems for nitrous oxide waste gas evacuation.
5. Each operating room will have overhead service columns, each of which will contain: Two oxygen, two medical vacuum, one medical air, one nitrous oxide, and one nitrogen terminal unit. Additional medical vacuum terminal units will be provided on three of the walls of the operating rooms.
6. The terminal unit grouping indicated will be per patient station/bed.
7. For equipment testing and calibration.
8. Special gases from remote manifolds.
9. Type, location, and number of terminal units will be determined by the using service on a selected basis.
10. Per work station.
11. Each utility center requires one each DA and one each OE.
12. Each dental work station will have one each counter mounted gas and air cock.

Centrally piped systems will be furnished and installed in accordance with NFPA Standard 99. Piped systems will be provided with properly located and sufficient shutoff valves and local area alarms in accordance with NFPA Standard 99.

Recommended mounting height for emergency shutoff valves is 1650 mm.

Gas outlets in medical patient care areas will be the quick-disconnect type, except 1,379 kPa nitrogen, which shall be DISS type.

Station outlets will bear the label of approval as an assembly under reexamination source of UL and be designed to provide the following features unless noted otherwise in this section or Table 17.

- Conform to requirements of NFPA Standard 99
- Preclude any mix of service and safety keyed to prevent accidental interchangeability of secondary equipment
- Be capable of being flush mounted; self-sealing requiring no dust cover with quick coupling capability and equipped with an adjustable valve mechanism to compensate for mounting variations
- Provide one-handed single-thrust mounting and one-handed fingertip release of secondary equipment
- Accept two-pronged connectors, each to its own function and both preventing twist or turn of the secondary equipment once connected

<u>Medical Air (MA)</u>: A separate, duplex compressed-air system independent from the laboratory compressed air system shall be provided and shall contain oil-free air compressors, air dryers, air filters, and line pressure controls. For medical compressed air systems (air at patients' room outlets and operating room use), a pressure of 345 kPa gauge will be maintained. There shall be 100% redundancy of this equipment to allow for maintenance work without necessitating shutdown of the system. The system design criteria shall be for 100% of system peak load to remain upon failure of a pump.

MA systems shall have continuous dewpoint monitors as required by NFPA Standard 99, duplex air dryers, and duplex storage tanks.

Medical compressed air shall be tested as above, and in addition all piping shall be tested at 20% above normal line pressure for a 24-hour period. The only allowable pressure changes shall be those caused by temperature variations.

Medical and dental air compressors will take their source of air from filtered outside atmosphere (air already filtered for use in operating room ventilating systems). Air will not contain contaminants in the form of particulate matter, odors, or other gases. The following pressures are required at the most remote outlet:

• MA General	345 kPa
• Dental Air (DA)	586 kPa
• Special Dental Air (SHDA)	1034 kPa
• Process Air, Door Operators	827 kPa

Process air need not be oil-free and must not be included as part of the same system as laboratory, medical, or dental air. Air for building system controls will be obtained from a separate compressor. Medical, laboratory, and dental air systems will be independent systems. Such systems will be fitted with refrigerated air dryers and five micron filters.

Dental air compressors will be sized in the same manner as the oral evacuation turbines. The storage tank will be a minimum twelve 12 times (in liters) of all individual air compressors' sizes (L/s).

Nitrous Oxide: Nitrous oxide will be supplied by a piped central system at a terminal unit pressure of 345 kPa in all hospital operating, cystoscopy, cardiac catheterization, angiography, and oral surgery rooms and other locations shown in Table 17.

Nitrogen: Nitrogen may be required in some NIH facilities as a central system. This requirement must be verified with users on a project basis. Research-grade dry nitrogen shall be supplied to laboratory modules, treatment rooms, operating rooms, etc. as required.

Nitrogen will be a central piped system with pressure-reducing valves and/or control cabinets provided in operating rooms and oral surgeries. For dental power use, 1,103 kPa gauge pressure will be provided.

A liquid nitrogen storage tank, vaporizer, and associated controls shall be located outside the building.

For facilities with limited nitrogen requirements, the A/E should consider feeding the system from manifolded cylinders located in a central area or building cylinder closets.

Manifolded cylinders with redundant components or cylinder backup and reserve alarm shall be provided to ensure an uninterrupted supply.

Carbon Dioxide: Carbon dioxide may be required in some NIH facilities as a central system. This requirement must be verified with users on a project basis. Carbon dioxide shall be provided to areas as required.

A liquid carbon dioxide storage tank, vaporizer, and associated controls shall be located outside the building.

For facilities with limited carbon dioxide requirements, the A/E should consider feeding the system from manifolded cylinders located in a central area or building cylinder closets.

Central carbon dioxide systems must have redundant components or cylinder backup to ensure uninterrupted supply to incubators.

Special Gases (Cylinder Gases, CG): Research and health care at the NIH have requirements for many different specialty gases, including helium, argon, hydrogen, oxygen, nitrogen, CO_2, and various gas mixtures.

Space shall allow for the proper storage of full and empty gas cylinders, including separate storage areas for flammable and oxidizing gases.

Cylinder restraints shall be provided in storage areas, local distribution closets, and at points of use in the laboratories.

Laboratory Air (LA): The laboratory compressed air system shall be designed utilizing the central plant compressed air system as the source of compressed air. This air is delivered at a pressure of 827 kPa. For new buildings, a duplex compressed air system shall be installed as a backup to the central system. The system design criteria shall be for 100% of the system peak load to remain upon failure of a pump.

The compressed air system shall be designed to provide air at a pressure of 276 kPa and a flow of 0.47 L/s at every outlet station. Laboratory building diversity factors may be used if these can be assessed. The compressed air risers shall be at the delivered power plant pressure, with pressure-reducing valves located at the main floor takeoffs to deliver the necessary zone pressure conditions.

Higher-pressure air and higher flow rates may be required for equipment usage. These requirements shall be assessed on a case-by-case basis and will be provided by the use of pressure-reducing valves.

The control plant air may require additional dehumidification and filtering if higher-quality air is required.

The laboratory compressed-air piping system shall be tested at a minimum test pressure of 1,034 kPa with oil-free dry nitrogen or air. This pressure shall be maintained, and all joints examined for air leakage.

Laboratory air shall be instrument-grade air, filtered to remove hydrocarbons and particulates and dried to -12^0 atmospheric dewpoint. Air quality shall be in accordance with the *Quality Standard for Instrument Air* as published by the Instrument Society of America.

D.17.7 Vacuum Systems

Each application shall be evaluated for the type of substance or products being evacuated and for the appropriate application of equipment type.

The exhaust from the piping systems shall be discharged outdoors and remote from air intakes or other openings in the building, and shall be protected from the entry of insects or debris. To prevent premature wearing of the pump vanes due to backflow of condensate into oil sump, a drip pocket, at least 250 mm in length, full line size, and a ball valve shall be installed at the exhaust port of each pump. Drip pockets are also required at the foot of exhaust risers.

Particular consideration shall be given to the sizing of exhaust lines so as to minimize backpressure on the pump.

Vacuum pumps shall be air cooled only. The design engineer shall specify a maximum acceptable noise level for the vacuum system.

<u>Laboratory Vacuum (LV)</u>: The LV system shall utilize two or more vacuum pumps and a receiver, except where an existing vacuum system is being connected. Pumps, whenever possible, should be of the single-stage rotary vane type. The system design criteria shall be for 100% of the system peak load to remain upon failure of a pump. Vacuum receivers shall have automatic drain traps to remove moisture from the system.

Users shall be consulted to determine if emergency power is required.

The LV system shall be capable of maintaining a vacuum of 6,561 kg/m^2 of mercury at the furthest inlet terminal from the central vacuum source, i.e; the vacuum pumps. If deeper vacuums are required, they will be generated locally with special vacuum pumps in the lab or lab support area. The system or pumps shall be selected for an operational range of 7587 to 8287 kg/m^2. The control settings shall be set to energize the pump at a vacuum of 7597 kg/ m^2 of mercury and to stop the lead pump at 8,633 kg/m^2 of mercury. Standard laboratory diversity factors may be used if they can be properly validated.

The pumping system sizing shall be based on 0.235 standard L/s at each vacuum inlet terminal. The pipe sizing shall be based on 1381 kg/m^2 of mercury as the total piping pressure system drop from the furthest terminal.

Before attaching the vacuum lines to the vacuum pumps, receivers, and alarm signaling system switches and gauges, each section of the piping system shall be subject to a test pressure of 1,034 kPa gauge by means of oil-free, dry nitrogen or air. The test pressure shall be maintained and each pipe joint inspected for leakage by use of soapy water or other suitable means.

A standing pressure test shall be performed after installing the vacuum system, including station inlets, but before attaching the vacuum lines to the vacuum pumps, receivers, and alarm switches. The test shall consist of subjecting the system to a pressure of 414 kPa gauge by means of oil-free, dry nitrogen or air. After allowance for temperature variation, the pressure at the end of 24 hours shall be within 34 kPa gauge of the initial pressure.

For laboratories which are considered biohazard research areas (BL3 and BL4 labs), a parallel HEPA filter system shall be installed upstream of the vacuum pump in the vacuum line from the area. Filtration of air and disinfection of biohazardous materials shall be provided locally by each investigator as required. Filtration devices shall be installed in a manner that will require maintenance by lab personnel when they become loaded. Bypass lines shall not be installed.

Designs shall include the installation of vacuum traps within individual lab areas to protect maintenance personnel from potentially unknown hazards.

Medical Vacuum (MV): MV is independent from LV systems and shall be designed in accordance with NFPA Standard 99. The vacuum source shall consist of two or more vacuum pumps which alternately or simultaneously on demand serve the vacuum system. The system design criteria shall be for 100% of the system peak load to remain upon failure of a pump.

MV will be used to evacuate wastes in surgery and patient rooms. Duplex vacuum pumps will be installed in these systems. MV will be used for evacuation in areas listed in Table 17.

Two different pressures are required:

- Central Vacuum 2417-3453 kg/m^2 of mercury
- Surgical Vacuum 6561-8635 kg/m^2 of mercury

A liquid separator will be provided on the suction side of pumps that are part of central and dental vacuum systems. Multiple cylinder pumps may be used. At least two vacuum pumps will be installed in these systems.

Vacuum requirements and pipe sizing will be determined in accordance with NFPA Standard 99 and based on the terminal units specified in Table 17.

Vacuum station wall outlets will be provided with a bracket to accommodate a 2-qt bottle equipped with a float cutoff. Serrated shank adapters will be provided for 30% of the vacuum wall outlets stations.

Master and local area alarms shall be provided for MV systems. A master alarm with noncancellable visual signals shall indicate low levels in the main line and shall be located in a continuously monitored location. If one continuously monitored location is not available, a secondary master alarm shall be installed where it is most likely to be seen or heard, such as a telephone switchboard or security office. All alarms shall be energized by the essential electric system.

Area alarm systems shall be provided in anesthetizing location areas and other life-support and critical care areas such as postanesthesia recovery, intensive care units, and coronary care units. Area alarms shall provide audible and noncancellable visual signals when pressure drops below 4144 kg/m^2 and shall be located at nurses' stations or other suitable locations.

<u>Oral Evacuation System</u>: A central, high-volume oral evacuation (HVE) system will generally consist of the following:

- Two vacuum turbine units and controls
- A water-air separator at the dental unit and a central separator located near the turbine suction
- Surge control devices and silencers for turbines
- An alternator or two-way switch to alternate starting of vacuum

turbine motors

- A piping system of corrosion-resistant material
- A low-voltage remote control system for system control and alarm

The system will be capable of producing a vacuum of 2762 kg/m^2 with a minimum airflow of 7 standard L/s at the remote aspirator tip, such tip having a 10 mm opening. The oral evacuation system capacity will be designed with usage factors as follows:

Number of Dental Treatment Rooms (DTRs)	Usage Factor (%)
1- 6	100
7-10	95
11-15	90
16-20	85

Based on the usage factor, each vacuum turbine will be sized to handle 60% of the calculated load. The vacuum turbines will be sequenced so that the second turbine will start upon demand. The piping system will be sized for maximum velocity of approximately 15 m/s and a minimum velocity of 10 m/s with no pipe size less than 40 mm in diameter, except that 20 mm diameter tubing will be used from the dental unit junction box to the main line. The pipe system will provide long radius bends and wye branches and will slope without low points to the separator. Vacuum relief valves will be provided at the end of each pipe run to ensure adequate transport velocity during periods of reduced usage. All values stated are based on standard condition (21 ^{0} and 101 kPa), and the performance rating will be compensated by project site. Cleanouts will be provided as part of the piping system. Operatory separators will be located as directed by the using service. Drains will be provided to dispose of liquid waste from the separators.

Exhaustor inputs will be connected in parallel. Each input will be equipped with a mechanical antisurge valve for vacuum control. The equipment manufacturer will furnish documented certification of each turbo exhauster as to its ability to handle the design loads without exceeding the normal operational limits of the exhauster or drive motor. Ingestion gates and antisurge valves will be preset to maintain specified design requirements for airflow and vacuum levels. The system will incorporate one or several central separators as determined by the following criteria:

Separator Tanks

Number of DTRs	Quantity	Size (liter)
1 - 6	1	76
7 - 10	1	152
11 - 20	1	304

D.17.8 Natural Gas/Fuel Systems

Fuel gas piping for NIH buildings is usually limited to natural gas which is supplied through site distribution mains from a Washington Gas source. Propane may be used for remote buildings when life cycle costing justifies its installation over natural gas.

All gas piping, tanks, etc. shall be designed in accordance with NFPA Standard 54/ANSI Z-223.1, National Fuel Gas Code.
The natural gas piping system shall be designed to provide 55 L/s at each laboratory outlet at a pressure of 1370 Pa gauge. For equipment requiring gas, the volume flow rate required shall be determined from the manufacturer's input ratings. A diversity, if safely established, may be used for the laboratory outlets, but equipment shall be considered at 100% use factor.

The design pressure loss in the gas piping system shall be such that the supply pressure at any piece of equipment is greater than the minimum pressure required for proper equipment operation. A pressure drop of 75 Pa water pressure during periods of maximum flow is considered to be a reasonable design guide for low-pressure gas installations.

At the NIH, cast iron, copper, brass, or plastic pipe and fittings shall not be used in natural gas systems. Black steel pipe with malleable fittings or other approved material in conformance with standards for metallic pipe, as set forth in Section 2.6.2 of NFPA Standard 54, shall be used. Shutoff valves shall have leakproof gas cocks.

Generally, gas piping shall run exposed and shall be graded 6 mm per 5 m to prevent traps. Horizontal lines shall grade to risers. Gas piping shall not be run in tunnels, furred ceilings, or other confined spaces where gas might collect and create a serious hazard.

Gas piping shall be tested with an air pressure of 5,160 kg/m^2 mercury. This pressure shall not have a pressure drop differential during a 1-hour period.

Green gas vents located within the building shall be piped outside. Valves for use in gas systems shall be UL listed as Fire-Tite. Gas cocks or outlets shall have 1/4-turn lever handles so that a quick visual observation can determine if valves are open or closed. Each floor must have an isolation valve that is quickly accessible for emergency shutoff.

D.17.9 Backflow Prevention (BFP)

BFP devices shall be installed in strict compliance with WSSC plumbing regulations. BFP devices shall conform with ASSE Standards as listed in the Code or be equivalent to AWWA and USC Standards. BFPs shall be used to segregate water supply systems, i.e., domestic water from industrial nonpotable, mechanical, and fire protection systems.

When a single water main enters a building from an outside WSSC distribution source, it shall be equipped with BFP to protect the main from all building users, including domestic. Domestic potable water, industrial nonpotable water, mechanical, and fire protection water supplies shall be independent of each other; these are taken from the main building supply, and these shall be provided with BFP as specified below.

Main domestic water and industrial water piping supply systems serving the building shall have two reduced-pressure double-check valve BFPs installed in parallel for each piping system. This avoids interruptions to water service when maintenance or testing is required. One device can be shut off while the other is left in operation. All BFPs shall have isolation valves at the inlet and outlet for testing and servicing.

A building structure with more than one source of outside water supply within the building shall be required to have one reduce pressure double-check valve BFP at each industrial and domestic water supply serving the structure.

Fire protection supply piping shall be equipped with a double-check valve to provide BFP, and it shall be located downstream from the fire protection shutoff valve. Any isolation or shutoff valve in the main line leading to or branch providing water supply for the automatic sprinkler system shall be OS & Y (outside stem and yoke) and be electrically supervised by the fire alarm system.

The mechanical equipment water supply main shall have a single, reduced-pressure double-check valve BFP installed.

Care shall be taken not to install reduced pressure BFPs in series with one another since they have a significant pressure drop. When the service main enters the building, each water system shall tap the main in a parallel arrangement thereby preventing the need for series BFPs. Design Engineers shall be sure to consider the peak pressure drop through BFPs when designing the distribution systems.

All laboratory water fittings shall be equipped with vacuum breakers in addition to a BFP installed on main.

Water system connections or outlets to individual plumbing fixtures, tanks, receptacles, or equipment shall be protected from backpressure as follows:

- Installation an approved air gap (preferred method)
- Where it is not possible to provide a minimum air gap, equip the supply connection with an accessibly located BFP (atmospheric-type vacuum breaker) installed beyond the last control valve
- For laboratory faucets with hose connections, through installation of an atmospheric-type vacuum breaker

Backflow devices shall be selected from the approved list available from the WSSC and installed as per the WSSC Plumbing Regulations. Application of backflow devices as listed in Table No. 18 shall be subject to field verification of hazards and conditions.

Table No. 18
Application of Backflow Prevention Devices

Standard Number	Device or Method	Type of Protection (BS = backsiphonage) (BP = back pressure)	Hazard	Installation Dimensions and Position	Pressure Condition (I=Intermittent) (C=Continuous)	Comments	Use
ANSI A112. 2.1	Air Gap	BS & BP	High	Twice effective opening - not less than 25 mm above flood level rim	C	See 404.4	Lavatory, sink or bathtub spouts. Residential dishwasher (ASSE 1006) and clothes washers (ASSE 1007)
ASSE 1001	Pipe Applied	BS	Low	- 150 mm above highest outlet - Vertical position only	I		Goosenecks and appliances not subject to back pressrue or continuous pressure
ASSE 1011	Hose Bibb Vacuum Breaker	BS	Low	- Locked on hose bibb threads - At least 150 mm above grade	I	Freeze proof type required	Hose bibbs, hydrants and sillcocks
ASSE 1012	Dual Check Valve with Atmospheric Vent	BS & BP	Low to Moderate	- Any position - Drain piped to floor (see 411.4.2b)	C	Air gap required on vent outlet Vent piped to suitable drain * See Footnote	Residential boilers, spas hot tub and swimming pool feedlines Food processing equipment Photo lab equipment Sterilizers Commercial dishwashers Water cooled HVAC Landscape hose bibb Washdown racks Make-up water to heat pumps

ASSE 1013	Reduced Pressure Zone Backflow Preventer	BS & BP	High	-Inside building - 450 mm to 1200 mm (centerline to floor) - Outside building - 450 mm to 600 mm (centerline to floor) - Horizontal only	C	Valves Per 404.3.3 Testing - annually (minimum) 404.3.8 Overhaul - five (5) yr. (minimum) per 404.3.9 Drain per 404.3.8 b	Facilities per 404.3.5 Chemical tanks Chilled water Cooling towers Commercial boilers, swimming pools, spas Heat exchangers per 404.5 Hospital equipment Lawn irrigation (Type II) Solar systems per 404.5 Submerged Coils Treatment plants Fire sprinkler (high hazard as determined by Commission)
ASSE 1015	Double Check Valve Assembly	BS & BP	Low	Inside building 450 mm to 1200 mm (centerline to floor) Outside building 450 to 600 mm (centerline to floor) Horizontal only 1500 mm required above device for testing	C	Valves per 404.3.3 Testing annually (minimum) per 404.3.8 Overhaul five (5) yrs. (minimum) per 404.3.9	Fire sprinkler system (Type II low hazard) Washdown racks Large pressure cookers and steamers

ASSE 1020	Pressure Type Vacuum Breaker	BS	High	300 mm to 1500 mm above highest outlet Vertical only	C	Valves per 404.3.3 Testing annually (minimum) per 404.3.8 Overhaul - five (5) yrs. (minimum) per 404.3.9	Degreaser Laboratories Photo tanks Type 1 lawn sprinkler systems and swimming pools (must be located outdoors)
ASSE 1024	Dual Check Valve	BS & BP	Low	Any position	C	* See Foot note	Fire sprinkler systems, Type 1 Buildings Outside drinking fountains Automatic grease recovery devices
ASSE 1035	Atmospheric Vacuum Breaker	BS	Low	150 mm above flood level	I/C per manufacturer		Chemical faucets Soft drink, coffee and other beverage dispensers Ice Makers Dental chairs Hose sprays on faucets not meeting standards. Miscellaneous faucet applications

*A tag shall be affixed to all ASSE 1012 and 1024 devices indicating:

a.Installation date.

b.The following statement: “FOR OPTIMUM PERFORMANCE AND SAFETY, WSSC CODE REQUIRES THAT THIS DEVICE SHALL BE REPLACED EVERY FIVE (5) YEARS”

D.17.10 Pure Water Systems

The quality of water distribution in a central building distribution system shall be a joint decision between research personnel, the A/

E, and the Project Officer. The water quality decision must reference an industry standard such as ASTM or be very specific as to the water conditions so that the Design Engineer can appropriately engineer the system.

The requirement for a very high-quality central distribution system will be expensive to install and cost prohibitive to maintain on a long-term basis. Most buildings are better served by a medium grade (ASTM Reagent Grade) system that utilizes local point-of-use polishing equipment for specific needs. Researchers generally do not have the confidence that the central system will have a consistent high quality, so they ultimately install polishing equipment anyway.

A water analysis shall be prepared during the design stage to determine the degree of treatment required. The water supplied will be softened to between 50 mg/L and 85 mg/L (3 to 5 grains per gallon). If specialized equipment requires water having a hardness less than 50 mg/L, a special study will be made to determine the most feasible means of obtaining water of the necessary hardness.

There have been numerous types and combinations of water systems installed at the NIH for laboratory use. Distilled water, deionized water, and a deionized water system containing a reverse osmosis unit have been installed in most applications. The current preference for the NIH is to have a central recirculating reverse osmosis system to supply general use water and to utilize local polishing equipment at specific point-of-use areas.

Where projects involve renovation work, new materials shall be identical to existing and be installed in a similar manner. The NIH will make all final connections to existing systems. Designers shall arrange piping so that a minimum number of connections are required to existing systems.

Type III grade water as specified in ASTM Standard D 1193 will be provided for heat exchangers used for steam humidification, hospital pharmacy, electrically powered sterilizers, hospital laboratories, distillation unit, glassware washing, and central material service. The NIH may require ASTM Standard D 1193 Type 1 water that will be supplied by a local subsystem. Additional systems and use areas for a specific project will be determined by the program of requirements.

Reverse osmosis will be considered for primary treatment with deionization or distillation for secondary treatment, as required at point of use to meet a specific requirement. The water purity obtainable with the different methods of purification are:

Reverse Osmosis	100,000 ohms
Deionization	15 to 18 mega-ohms
Distillation	800,00 ohms to 1 mega-ohm and bacteria free on triple-effect

Reverse Osmosis (RO) Systems: The RO systems should be located in the building penthouse to reduce pressure on system components and to minimize the storage capacity of tanks. The RO systems consist of a series of built-up components which may include the following:

- Automatic backwashable multimedia filters
- Automatic backwashable carbon filters
- Automatic regenerable softener
- Duplex 1 micron prefilters
- Reverse osmosis unit
- Storage tanks
- Tank controls and filters
- Duplex recirculation pumps
- Polishing service deionization tanks
- Resistivity metering equipment
- Ultraviolet sterilizer
- Postfiltration system

Distilled Water Systems: Distilled water may be obtained from a central distilled water system or from a still located within the laboratory. Steam is utilized in production for central distilled water systems, whereas electricity is used for small local systems.

For central systems, titanium distilling equipment and teflon- or titanium-lined storage tanks shall be sized to assure an adequate daily volume of water. Multiple stills and tanks shall be utilized to allow downtime for maintenance purposes. Still size shall be determined on the basis of 24-hour operation of the stills and the provision of adequate storage tank capacity. Local stills shall be made of glass.

Piping, fittings, and the wetted parts of valves shall be made of perfluoroalkloxy PFA Teflon, plastic: ASTM Standard D, Schedule 40 PFA.

Stills should be installed in nearby mechanical rooms to minimize the piping distribution of distilled water and be placed at an elevation within the building to enable gravity flow to the outlets in the piping system. Mechanically pressurized systems are not recommended, since the pump and fittings may introduce impurities in high-quality water.

Where distilled water is not required but a water quality that is better than deionized water is needed, a local water-polishing system made up of filters, a reverse osmosis unit, and a cation unit/ anion unit, and a mixed-bed unit may be installed.

Distilled water systems shall not be cross connected with any other water system such as deionized, RO, or local water-polishing systems.

Deionized Water Systems: Deionized water is used for experiments and washing laboratory glassware and equipment. Generally, a central deionized water system is not used to supply deionized water throughout a laboratory building but supplies the water to a central washing facility. Small deionized equipment is utilized locally for individual laboratory requirements. The A/E shall determine through consultation with the research personnel and the Project Officer the requirement for a central washing system and local laboratory systems.

Deionized water systems shall consist of filters, cation exchange units, ion-exchange units, and mixed bed units. A means for measuring and totalizing flow from the exchange units and to measure the resistibility of the deionized water shall be provided. Regeneration systems shall be provided for central systems. Deionized water shall be recirculated through a reverse-return piping system and filtered to maintain high purity.

The A/E shall provide to the NIH all information, including drawings, specifications, cost data, supplier list, and system requirements, so that the NIH can advertise a separate contract for supplying, maintaining, and regenerating the deionizing equipment.

System Sizing: The Design Engineer must clearly define sizing param of the systems including total daily consumption, peak system flow, hourly system flow, distribution flow to each floor or zone, and maximum flow per outlet. Pure water systems normally have a large diversity between low- and high-flow conditions with multiple peaks sometimes occurring throughout the day. Each floor or zone must be balanced in the field to provide a predetermined quantity of water so that all research functions are satisfied.

It is critical that the Design Engineer receive a signed-off system schematic and design criteria document for the pure water system before the design is completed. Design param tend to change during the construction phase as equipment technology evolves and final equipment selections are made. The water system designs, to the extent practical, shall consider future requirements, pressure and flow changes, and water quality improvements.

Pipe materials and sizing shall be consistent with the defined system param. The piping system material will be compatible with the degree of water purity required. Piping, valves, fittings, and fabrication techniques will be selected on the basis of the ability of each item to handle pure water without inducing reionization or recontamination. Pipe sizes shall limit excessive verocity and pressure drop while preventing low flow or stagnant conditions in the distribution. Dead legs shall be avoided where possible, and floor branches shall be recirculated.

All pipe and pure water system sizes and components shall be reviewed and approved by the system vendor. The entire system, including piping and outlets, shall be provided by a sole-source contractor or vendor so there is a single point of responsibility for the successful operation of the system.

D.17.11 Process Water Systems

Animal Watering System (AWS): The AWS must be separated from the domestic water system with a reduced-pressure BFP.

The need for an AWS and the quality of water to be utilized in the AWS must be determined by the users and animal care staff. The type and quality of water depend on the type of animal populations, the type of research being conducted, and the quality of domestic water supply. The domestic supply may be adequate for many types of animals and research. However, in other applications treated water may be required. Treatment may include reverse osmosis, deionization, or may require chemical injection.

Specific requirements for the zoning, number of water connections per room, control, injection capability, flushing, and recording/ monitoring must be verified with the users.

When automated watering systems are used, a manifold for flushing hose coils is required in the cage and rack washing area.

All pipe and watering system sizes and components shall be reviewed and approved by the system vendor. The entire system including piping and outlets shall be provided by a sole-source contractor or vendor so there is a single point of responsibility for the successful operation of the system.

Research Equipment: Research equipment such as lasers, NMRs, mass specs., etc. often requires a water source for cooling and adequate drainage facilities. Where possible, such equipment shall be connected to the process-cooling water system and recirculated for reuse.

Where equipment operating conditions, pressure requirements, temperature limitations, or backpressure restrictions require the use of a plumbing water source, the industrial water system shall be used.

Equipment connections frequently require pressure-regulating valves, relief devices, balancing valves, flow controllers, and temperature regulators to complete their installation.

Drainage connections must always be indirect and sometimes require gravity flow. Flow sinks on other large open-site drains are used to handle the large intermittent discharges.