SECTION 15500 – "HVAC SYSTEMS"

1.0 Types of Systems

A. HVAC systems 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, 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 are 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.

B. Proposed system alternatives must be evaluated fairly with consideration given to operating and maintenance costs, reliability, flexibility, durability, 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.

2.0 All-Air Systems

A. 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 the space-sensible cooling or heating load. 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.

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

C. 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).

D. 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.

E. 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.

Areas or spaces that require 24 hour operation, such as communications rooms, electrical rooms, data centers and other process areas, shall be provided with dedicated systems.

F. The usage of cold (low temperature) air distribution may not be considered for an energy conservation or cost saving method due to the supply temperature of central chilled water system.

The chilled water supply temperature varies based on the following outdoor conditions:

OUTDOOR TEMPERATURE	CHILLED WATER SUPPLY TEMPERATURE
> 45 Degree F	45 - 47 Degree F
< 45 degree F	Up to 55 Degree F

Therefore, systems with winter loads such as data centers and telecom rooms utilizing chilled water service to provide cooling, equipment shall be sized based on the winter chilled water supply temperature.

G. A high chilled water temperature rise in the coil is required to reduce pumping horsepower and to increase the efficiency of refrigeration equipment. A minimum 15^{o}F rise is recommended, and in some cases a rise as high as 17^{o}F can be economically achieved.

H. The chilled water coil face velocity should not be more than 400 FPM on new installations and 450 FPM on replacement units. A low face velocity requires a larger 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, and prohibits future load growth.

I. The aspect ratio (ratio of width to height) of rectangular ducts should be minimized to reduce pressure losses and initial costs. Duct aspect ratios should not exceed 4:1.

3.0 Air and Water Systems

A. 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.

B. 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.

C. Two pipe 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. These FCU shall be sized for a 55 F EWT.

D. 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.

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

F. Variable Frequency Drives (VFDs) shall be considered for use on applicable fan and pumping systems with motors greater than 5 horsepower.

4.0 Unitary Equipment

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

5.0 HVAC System Noise Criteria

A. **Duct lining is not permitted for use in duct systems.** Omission of duct lining usually requires sound attenuators in order to meet the specified Room Criteria (RC) levels shown below. The A/E should confirm that any breakout noise from ductwork passing through a space does not violate the specified RC criteria. A sound analysis shall be performed to ascertain the need of terminal sound attenuators.

B. Maximum noise criteria levels to be used in the HVAC equipment and distribution design are outlined below. These noise criteria levels are based upon an unoccupied space with only the mechanical systems operating, and do not take into account any noise generated by users, animals or equipment. Readings are assumed to be taken in the center of the room, nominally five (5) feet above the floor, unless noted otherwise.

The maximum sound pressure level in any octave band frequency shall be the Room Criteria (RC) Neutral (N) upper level limits (5dB above the RC curve within 31.5 to 500 Hz octaves and 3dB above the RC curve within 1000 to 8000 Hz octaves). The Room Criteria (RC) levels are as explained in the latest ASHRAE Fundamentals Handbook.

Criteria for space maximum noise levels from the HVAC systems. All levels are measured in the center of the room unless noted otherwise.

***Laboratories*: RC50(N) maximum allowable HVAC noise level as measured from nominally three (3) feet from fume hoods.**

***Laboratory Equipment Support Rooms*: RC50 (N)**

***Animal Hold Room*: RC50 (N)**

***Animal Procedure Room*: RC50 (N)**

***Vivarium Support Rooms (Cagewash/Glasswash Rooms)*: RC65 (N)**

***Private Office*: RC35 (N)**

***Open Office*: RC40 (N)**

***Conference Room*: RC35 (N)**

***Auditorium*: RC35 (N)**

***Classroom*: RC35 (N)**

***Mechanical Rooms*: 80dba. maximum allowable HVAC system noise level a measured from the center of the room. This criteria may not be able to be achieved in all mechanical rooms (such as chiller rooms). A program of hearing protection will need to be considered in some mechanical spaces.**

C. 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 be fabricated to match the construction and pressure classification of adjoining duct or casing and be constructed of incombustible materials.

Filler materials used in sound attenuators on clean systems shall be inert, vermin, and moisture-proof and shall have an approved moisture and particulate lining material between perforated metal panels and sound-attenuating filler material to prevent insulation fibers from becoming airborne.

Sound attenuators used in contaminated exhaust systems shall be packless utilizing controlled-impedance membranes and broadly-tuned resonators for attenuation. No sound-absorptive material shall be used in the packless sound attenuators.

6.0 Plenums

A. The use of air shafts for air distribution (supply, return, or exhaust) is not permitted. 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 National Building Code.

B. The use of building structures as plenums shall be limited to outside air intakes. The use of return air plenum ceilings is not permitted. Ducted return (including drops) air ductwork shall be extended (at a minimum) from the return air duct shaft to approximately 2/3 to 3/4 of the distance to the farthest extremity of the space.

7.0 Indoor Air Quality

A. Providing acceptable indoor air quality (IAQ) is the responsibility of the A/E. Typical contaminant control measures include elimination of contaminant sources, dilution ventilation, local exhaust ventilation, and air cleaning.

B. The mechanical ventilation system should be designed to maintain relatively comfortable and odor-free indoor spaces.

C. The A/E should consider the various sources of air contamination that would contribute to poor indoor air quality conditions. These sources may occur from building materials and systems, originate in outside air, and/or be from building operating and maintenance programs and procedures that may foster growth of biological organisms. These sources would include, but not be limited to, the following:

1. Non-biological particles such as synthetic vitreous fibers, combustion nuclei, nuisance dust, etc.
2. Bioaerosol particles include airborne viruses, bacteria, pollen, and fungus spores.
3. Gases and Vapors that may be generated by industrial process, by emissions from building materials, furnishings, and equipment, by occupants and their activities in a space, brought in from the outdoors, or by entry from surrounding soil (e.g.: radon gas). Volatile Organic Compounds (VOCs) are generated by emissions from new construction materials (furniture, furnishings, wall and floor finishes, paint and adhesives).

D. The A/E should consider the following strategies (or combination thereof) that may be used to improve the indoor air quality:

1. Elimination and control of Sources: Many sources can be eliminated or minimized by substitution of materials and control measures that include careful planning; specifications; and selection, modification, and treatment of products, as well as special installation procedures. **Another example of source control would be limiting or prohibiting vehicular traffic or parking in the vicinity of building outdoor air intakes. Designated smoking area in the vicinity of outside air intake is another common problem.**

2. Ventilation: Dilution ventilation is an effective way to control normal constant-emission sources present in buildings. Compliance with ASHRAE Standard 62 should satisfy indoor dilution ventilation requirements.

   System operation with 100 percent outdoor air should be considered for use at the completion of construction or during and at the finish of remodeling or renovation activities. Operation with 100 percent outside air would continue until enough time has passed to lower emitted contamination concentrations to near background levels.

3. Local Exhaust: Local exhaust ventilation is effective for controlling known, unavoidable point emissions sources such as office machines, food service equipment, and specialized work areas (printing rooms, photo labs, etc.).

4. Ventilation Air Cleaning: Gas Phase Air Filtration should be considered to control gaseous contaminants to provide ventilation without the need of additional outdoor air, or to clean poor-quality outdoor air. Particle Filtration shall be used to reduce the level of airborne particles that may be harmful to humans, such as airborne microorganisms and respirable particles. It is also effective to lower the particular matter in the ventilation system components where wet surfaces are present. Dirt accumulation on wet surfaces provides a substrate that may lead to microbial growth which in turn causes the ventilation system to become a source of contaminants.

E. ASHRAE Standard 62 – 2001 (and approved addenda) shall be used to determine ventilation rates.

Where significant variations in occupancy patterns occur, the A/E shall incorporate a ventilation control system that sequences, as close as possible, the quantity of outdoor air based on actual building occupancy and under any thermal load conditions. The ASHRAE Standard 62-2001 "Indoor Air Quality Procedure" permits the use of innovative, energy conserving practices, utilizing whatever amount of outdoor air quantity necessary to maintain levels of indoor air contaminants below recommend levels. This procedure shall be used whenever credit is taken for controls that remove contaminants or for other design techniques that can be reliably demonstrated to result in indoor contaminant concentrations equal to of lower than those achieved using the Standard's "Ventilation Rate Procedure".

The ASHRAE Standard 62-2001 Ventilation Rate Procedure is a prescriptive approach in which outdoor air intake rates are determined based on space type/application, occupancy level and floor area. This procedure may be utilized where occupancy rates are know to be constant, or in systems that would not otherwise result in the economic benefits of using outdoor intake controls to track space occupancy.

F. The A/E should identify and respond to air contaminants impacting outdoor air intakes or other infiltration sites. Outdoor air contamination from, but not limited to, the following sources of contamination should be considered:

1. Motor vehicle exhaust from garages, parking lots, roadways, loading docks and emergency/standby power generators.

2. Cooling Towers.
3. Localized exhaust and relief air systems from adjacent openings or other nearby buildings.
4. Sewer vents.

Where the possibility exists that flow patterns and turbulence of wind passing over a building can cause recirculation of exhaust gases to air intakes, an evaluation should be performed by the A/E to determine the effects of wind on intakes and exhausts. On small projects, or less critical applications, accepted ASHRAE methodology may be used to evaluate these effects. On larger projects or any critical application, such as where health and safety are of concern, physical modeling (wind tunnel exhaust dispensation study) should be used. The possibility of snow infiltration at intakes should also be evaluated.

8.0 Air-Handling Systems for Laboratory Buildings

A. 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:

1. The amount of fume hood exhaust required to meet actual design requirements of 6 air changes per hour (ACPH) or the ACPH rate set by Environmental Health and Radiation Safety Office (OEHRS) Standards for each type of laboratory.
2. The required space cooling loads. This is primarily a function of thermal transmission, solar loads, associated laboratory support equipment, and lighting loads. The A/E shall address loads in specialty laboratory equipment areas. A combined laboratory equipment and lighting load density of 12 W/FT^2 shall be used as a minimum in design of laboratory areas (9 W/FT^2 for equipment, 3 W/FT^2 for lighting).

B. 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. The duct system shall be so designed to accommodate future renovations as described in project criteria, and without a disruption to the entire system. Consideration shall be given to plenum and duct sizing and the addition of isolation dampers and duct risers to accommodate future use of the facility.

C. Critical 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 shall 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. Critical elements will vary on a project to project basis, therefore equipment/system design parameters shall be documented during the programming stage of the project to establish conformance to this criteria.

D. 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 100 percent system capacity. 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. All equipment requiring maintenance such as exhaust fan motors, drives, valves, damper operations, controls, limit switches, etc., must located out of the airstream and be accessible without the shutdown of the exhaust system. Each fan shall be fully isolated from the others to accommodate routine service while the overall system is operational.

E. Where laboratory space pressure is required to be maintained, supply and exhaust air from laboratory equipment such as fume hoods and biosafety cabinets, and general central laboratory exhaust systems is preferably controlled through pressure-independent terminal units such as a Phoenix Control System. The A/E shall investigate other system control options for reliability, accuracy, and safety.

F. Exhaust and supply fans shall be energized and shutdown sequentially. Part of the exhaust shall be started first, and sequentially the supply started to maintain a negative pressure in the exhaust duct and prevent cross contamination. Similarly, during the shutdown sequence, the supply fan(s) shall go down first and sequentially deenergize the exhaust fans. The procedure shall take into account the pressure rating of the fans, duct, windows, doors, etc. to prevent implosion of ducts, windows, doors, etc.

G. **No positively pressurized segment of any laboratory exhaust system shall be located in any occupied zone**. 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, including mechanical areas. The positive pressure segment of exhaust system shall be constructed per the SMACNA standard for 6.0 in. 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. For duct leakage testing requirements for all other systems refer to Section 15890.

H. When fume hoods are connected to common exhaust systems the entire exhaust system shall be provided with pressure independent air volume control devices such as a Phoenix Control System. .

I. All toilet and general use exhaust shall discharge through an exhaust system that is separate from the lab exhaust.

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

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

L. 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. Ductwork from these devices shall avoid long horizontal runs. Moisture eliminators should be considered for use at hoods.

M. As a minimum, supply air for lab areas shall pass through a prefilter and filter on the upstream side of AHU fans and coils with efficiencies of 30% and 95% respectively, based on ASHRAE Standard 52.1, 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 Office of Environmental Health and Safety, where specific hazardous program functions occur.

N. Where specific areas require special exhaust air treatment, such as HEPA filtration, consideration shall be given to providing separate dedicated exhaust systems. The A/E should demonstrate that the cost of a separate system would be offset by the penalty that would be otherwise imposed by including special filtration, and the associated higher static pressures, on larger systems for only a small number of spaces.

O. Ventilation of environmental rooms shall be addressed on design documents. Those rooms that serve as occupied functioning lab spaces shall receive conditioned outdoor air ventilation at the rates defined by ASHRAE Standard 62- 2001. The A/E shall evaluate special requirements required to maintain conditions in these spaces, including, but not limited to, the following considerations:

- Requirement for humidification/dehumidification of ventilation air.
- Criteria for environmental room accuracy across the entire volume of the space.
- Need for redundant equipment.

Environmental rooms used primarily for storage functions do not require ducted ventilation air.

P. Systems that require humidification are to be of the dry-steam, manifold-jacketed type and be located in the AHU up-stream of the Chilled Water coil. 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.

Q. 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. This concept is project specific and is to be reviewed on a case by case basis with The Office of the University Engineer. The central supply and exhaust air `system shall be sized based on the following procedures:

1. List the individual room total air requirements accounting for hoods, sensible heat loads, and maximum air change rates.
2. Add approximately 5% of the system design air quantity to the total system air flow rate to account for duct leakage.
3. Size all AHU system components and duct mains to allow for future expansion and renovations in accordance with specific criteria furnished by The Office of the University Engineer.
4. 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.

9.0 Air-Handling Systems for Vivarium Buildings

A. The air-handling system design shall comply with the requirements described in the *Guide for the Care and Use of Laboratory Animals,* current edition, NIH, AAALAC and AALAS Standards. 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 terminal humidity control where required. Minimally individual temperature control must be provided for each holding room, treatment room, procedures room, operating room and other support spaces. 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:

1. Minimum ventilation requirements of 15 supply outdoor air changes per hour in all holding spaces without ventilated racks and support spaces. Lower air change rates can be considered for other support areas such as storage areas, etc.
2. The amount of fume hood, biosafety cabinet, and downdraft table exhaust required to meet actual program requirements if there are animal research laboratories and procedure rooms within the facility
3. 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.
4. Minimum ventilation requirements as required to support microenvironments in ventilated cage racks are as follows: if microenvironments are employed for

animal holding, the minimum ventilation requirement may be reduced to 10 supply outdoor air changes per hour. System connections to microenvironments shall be designed to maintain the manufacturer specified criteria. The preferred arrangement for ventilated cage racks is ducted exhaust. Exhaust connections shall accommodate positive or negative ventilated racks.

B. A critical component to particular vivarium facility design is the ability to reverse pressurization on the room level as well as the microenvironment level. During the project programming effort, pressurization requirements shall be determined and system control measures shall be reviewed with The Office of the University Engineer.

C. During the programming of the vivarium spaces, the functional flexibility of animal holding spaces shall be determined and HVAC systems designed accordingly. Not only the present and future requirements for housing large and small animals and specialty species (such as rabbits) shall be determined but also the requirements to switch occupancies from one function to another shall be considered in the HVAC system design.

D. HVAC systems serving animal facilities shall be designed with manifolded parallel heating, ventilating, and air-conditioning system arrangements with capability to ensure continuous operation (full airflow) during equipment failure and scheduled maintenance outages. Parallel operation of two or more pieces of equipment operating at reduced capacity to meet the full load may be considered to meet redundancy requirements in lieu of providing dedicated spare equipment. 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.

E. The exhaust system shall be designed for and utilize a manifolded 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, system shall maintain 100 percent system capacity. 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. As an alternative, parallel operation of two or more fans operating at reduced capacity to meet the full load may be considered to meet redundancy requirements in lieu of providing dedicated spare fan. 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.

F. In buildings housing both vivariums 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.

G. All toilet and general-use exhaust shall discharge through an exhaust system that is separate from the variorum exhaust systems.

H. The HVAC designer is required to get approval from the Office of Environmental Health and Radiation Safety (OEHRS) regarding exhaust mixture compatibility and filtration.

I. As a minimum, supply air for these areas shall pass through a prefilter and after filter with efficiencies of 30% and 95% respectively based on ASHRAE Standard 52.1, 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 OEHRS, where specific hazardous program functions occur. The location of air handling unit filters shall be determined on a project by project basis. Final filtration at the air handling unit level shall be reviewed with the OEHRS. Exhaust systems from vivariums shall have the capability of being centrally HEPA filtered. Space and fan power requirements shall be planned for the addition of filters in the future. All exhaust air passing through heat recovery coils shall be filtered with a 30% efficient filter based on ASHRAE Standard 52.1 atmospheric dustspot test efficiency.

J. High-efficiency particulate air (HEPA) filtration of supply air may be required for animal-holding rooms housing immunosuppressedor transgenic populations or where populations are involved in chronic testing. Where HEPA filtration is required, consideration shall be given to providing separate dedicated exhaust systems. The A/E should demonstrate that the cost of a separate system would be offset by the penalty that would be otherwise imposed by including HEPA filtration, and the associated higher static pressures, on larger systems for only a small number of spaces.

K. 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.

L. In animal holding rooms, supply air must be introduced and extracted by air terminal devices that produce the most even control of temperature in the holding rooms and uniformly drawn across animal housing areas to low air exhausts located on the far side of the animal cages or racks. 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 24 inches from wall surfaces must be less than 50 FPM, or in critical areas, 30 FPM at head height.

M. Humidity control can be 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 shall be used to introduce potable plant steam supplied by the central site steam system into the HVAC system. The requirements for terminal humidification control vs. central humidification shall be examined on a project by project basis.

N. Provide backup emergency system (generators, chillers, etc.) in case of central system failures for critical applications.

10.0 Air-Handling Systems for Administration Buildings

A. Air-handling systems for academic, administrative, office, conference, and other general use facilities are similar in design. These systems are recirculating type with ventilation rates designed to meet ASHRAE Standard 62-2001 and approved addendum. Designs shall include air side dry-bulb economizers to provide free cooling when ambient conditions permit.

B. 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.

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

1. Night setback and morning warm-up control modes
2. Mixing plenums with minimum and maximum outdoor air dampers to accommodate minimum ventilation and economizer operations
3. 30% efficient prefilters and 95% efficient final-filters up-stream of the coils.
4. Preheat coils to support morning warm-up functions and large OA requirements.
5. Draw-through chilled water coils
6. Central AHU humidifiers only

7. Duct distribution to terminal control devices as necessary.
8. Return air systems shall be provided with building pressure controlled relief devices.
9. Return air plenum ceilings may not be utilized. Return air ductwork shall be extended from the return air duct shaft to approximately 2/3 to 3/4 of the distance to the farthest extremity of the space.

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

E. 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 temperature control.

F. Perimeter radiation shall be utilized paying special attention to areas with glass exposures, and where furniture layouts place sitting areas near or adjacent to perimeter walls. The perimeter radiation shall be exclusively controlled based on exposure by zone, (N., S., E., W.) sum load, and outside temperature.

G. Toilet rooms, janitor facilities, pantries, copy rooms, and other miscellaneous spaces generating odors or contaminants require exhaust to remove odors and contaminants from occupied areas. Toilet rooms and janitor closets shall not be connected to common exhaust systems and shall 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.

11.0 AHUs and Components

A. The type and construction quality of AHUs approved for 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:

1. Air-handling systems that are generally small in capacity (less than approximately 40,000 CFM), utilize return air, and are not serving critical program functions may be factory packaged or modular constructed components.

2. Large, central station AHUs (greater than approximately 40,000 CFM) that are recirculating or any size unit that uses 100% outdoor air shall be a custom-designed, factory-fabricated and tested unit. All exterior mounted units shall be a custom designed factory fabricated and tested unit. Factory personnel must be present the entire time it take to field install (set) the unit. A/E shall not limit the selection of a custom designed unit to the above CFM ranges, but should also consider other parameters such as pressure class, criticality, or other project conditions that may warrant the use of a custom designed unit. AHU with EPDM roofing is to meet FM approval 190 MPH roofing system requirements and be installed by a local roofing contractor. Each unit shall be tested by the unit manufacturer prior to shipping, as follows:

   a. Factory Test: Air volume and discharge static test shall verify that the air volume is within the range of 100% to 110% of scheduled nominal CFM requirements when operating at design total static pressure. The test for airflow and static capability shall include airflow measuring devices installed in all ducts returning to or leaving the unit. These devices shall be installed in accordance with the measuring device manufacturer's recommendations. Pressures external to the unit shall be simulated using a combination of ducts and dampers. The tests shall prove design airflow and static capability of the assembled unit.

   b. Factory Test: Casing leakage tests shall be run to prove that unit casing leakage is less than 1% of design flow at 12.0" w.c. The duct openings in the pressure section shall be sealed and this section shall be tested at 12.0"w.c. The CFM of this fan shall be read using and approved airflow measuring device. When the static pressure developed by the test fan reaches 1.5 times the unit design static pressure, the fan CFM shall be read and this CFM will be considered the casing leakage. The casing leakage must be less than 1% of the design CFM. Factory casing leakage test for fully welded units may be deleted. However, leakage test must be performed at the site after joining and sealing of sections for <u>all</u> unit construction types.

   c. Factory Test: The duct openings in the suction side of the unit shall be sealed and this section shall be connected to a test fan capable of developing a suction that is numerically equal to 1.5 times the design static pressure. The CFM of this test fan shall be read using and approved airflow measuring device. When the suction developed by the test fan is numerically equal to 1.5 times the unit design total static pressure, the fan CFM shall be read and this CFM will be considered the casing leakage. The casing leakage must be less than 1% of the section's design CFM (supply/return). Leakage across the septum wall located the discharge end of the fan shall be 0 CFM (no leakage).

d. Factory Test: Both the casing leakage test and the airflow and static capability test, as defined above, shall meet the required acceptance criterion without the use of any temporary caulking at any permanent panel joints. Temporary test caulking shall be utilized at the unit shipping splits to simulate "as installed" conditions.

e. Field Pressure Test: Pressurized leak testing shall be performed in the field after assembly of the unit sections by the HVAC Contractor, under the direction of the unit manufacturer, by running the fans and soap bubble testing all field joints and penetrations to ensure unit tightness. The unit manufacturer shall correct and pay for the repair of all deficiencies found during testing, except for the repair of all deficiencies found during testing, except for unit section joints leaks, which shall be the responsibility of the HVAC Contractor. The HVAC Contractor shall provide all field labor necessary to join the unit sections, including all electric and drain splits after they are delivered to the site and set in place. All fieldwork shall be provided under the direct supervision of a qualified engineer employed by the unit manufacturer. <u>Rigging for unit sections shall be provided by the HVAC Contractor.</u>

f. Factory Test Sound

  1) System sound levels shall be measured in all nine (9)-octave bands (31.25 Hz through 8000 Hz) at system design operating conditions. Airborne sound levels at all openings shall be read in the test ductwork 5'-0" from the openings. Transmitted sound levels shall be read 5'-0" from the outside of the fan section.

  2) Sound tests shall be conducted while the unit is running at design conditions. An octave band sound pressure level reading shall be taken at outside louver, exhaust louver, supply discharge opening, return air opening, economizer opening and adjacent to each fan section outside of the unit

casing.

g. Factory Test Vibration: Each individual fan shall be tested for vibration in X-Y-Z directions at the manufacturer's facility before shipment to the unit manufacturer to assure that specified fan balancing criteria is adhered to.

h. Test Procedures
   1) A complete test procedure shall be submitted to the Architect for approval detailing the methods, equipment, and techniques to be employed for each specific test. Equipment will not be considered approved until written approval of testing procedures is attained.
   2) As hereinbefore specified, the preceding airflow/static, sound and vibration tests shall be required for two AHUs specified in this Section and shall be witnessed by designated representatives of the Engineer and Owner (total [3] people). All unit sections shall be leak tested at the field after installation. The unit manufacturer shall notify the engineer and the University of Pennsylvania Department of Physical Plant Project Engineer for their approval. The unit manufacturer shall pay for all air and ground transportation, lodging, and meals for the designated witnesses to attend the testing. If multiple trips are required, they shall all be paid for by the unit manufacturer.
   3) Any deficiencies in unit performance must be corrected by the unit manufacturer in the manufacturing plant prior to shipping.

3. 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.
4. Electrical Interface/Work

a. The unit manufacturer shall furnish and install a complete factory wired electrical system for each unit, so as to allow single-source responsibility and to ensure proper selection and installation of all electrical components.

b. The unit manufacturer shall provide prewired and switched noncorroding vaportight fluorescent lights in each compartment with an access door and in the service corridors as follow:

1) Lights shall be equal to Appleton 4' –0' FRS Series, suitable for use in wet and dam locations.
2) Lighting, internal wiring, switching mounted in bell boxes, and all other electrical wiring associated with the lighting shall be provided by the unit manufacturer, at the Factory.
3) Lights shall have 120-volt cold weather (-20 F) ballasts and shall comply with UL 1570 and shall carry the UL label.
4) Unit manufacturer shall provide (2) 120 volt, single-phase electric connections for the lights and receptacles, via junction boxes with circuit breakers for connection in the field by Electrical Contractor (20 amperes power supply).

B. The Design Development 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.

C. Factory packaged or modular constructed AHUs, when approved for use, shall conform to the following criteria:

1. Units shall be of a modular design and have double-wall casing for all component sections.
2. The unit's coil capacity must be able to handle up to 100% outdoor air when required without moisture carryover.
3. All unit components must have large access doors to permit inspection, routine service, and cleaning. To minimize leakage, the quantity of access doors should be limited to those locations most likely to require access for routine maintenance. Generally these locations would be for access to fans, coils, temperature sensing devices, and filters. Clearly identified removable panels should be provided at other locations (e.g., at coils for coil cleaning purposes, at damper locations, etc.). Provide access doors approximately 20 inches wide by full height of casing or maximum of 60 inches. Swing doors against the air pressure.
4. Unit casings shall be pressure rated for the total system design operating pressure plus 25%.
5. Fan sections, where possible, shall employ airfoil fans with a minimum ACMA Construction Class of II.
6. Fan sections shall be isolated from the remaining unit and the connecting duct system to control vibration.
7. Solid fan shafts only will be considered.

8. External fan motors are preferred, and in all cases bearing lubrication lines shall be piped exterior to the casing wall.
9. Fan volume may be led control using variable frequency fan drives.
10. Units may be either draw-through or blow-through arrangements.
11. Coil drain pans shall be stainless steel and have a positive slope-to-drain connection. Drain connections to be off the bottom of the coil rather then the side.
12. Provide thermal breaks in units downstream of cooling coils.
13. Factory filter/mixing boxes may only be utilized for low-outdoor-air units and where filtration is limited to 30% prefilters.
14. Built-up filter/mixing sections utilizing high-quality low-leakage dampers and filter frames installed within insulated metal casings are required for all other units.
15. Each unit shall have adequate space to house, service, and maintain all ancillary equipment, controls, valves, instruments, etc.
16. Refer to Section 15790 "Air Coils" for coil design parameters such as maximum face velocities, fins per inch, etc.
17. For recirculation systems, consider eliminating the preheat coil where reheat coils can pick up the load and there is no building warm-up or outside air purge required.
18. Specify that variable temperature glycol systems are preferred for preheating to control to ± 1 degree F. A separate in-line-pump shall be utilized to maintain a constant flow through the preheat coil. Control to be preformed via a mixing valve based on mixed air temperature if multiple systems are connected.

D. 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:

1. 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.

2. 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 construction, minimum No. 14 gauge galvanized steel and an interior shell of No. 20 gauge galvanized steel [or aluminum]. A solid interior shell shall be provided upstream of prefilters and downstream of final filters and cooling coils. Remaining sections can have perforated interior shell.
3. 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 (24 inches x 72 inches), have vision panels, and seal with the air pressure.
4. All exterior units are to be custom designed with a heated service corridor as part of the unit. All controls and ancillary devices are to be accessible.
5. 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. Provide a duplex GFCI electrical outlet inside each motor section. Outlet shall be controlled from the outside by a separate switch. All wiring shall be provided by the unit manufacturer.
6. Unit louvers shall be ACMA rated and selected for low-pressure drop with less than 0.14 ounces/FT^2 penetration at 750 FPM 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.
7. Dampers shall be low leakage, and opposed or parallel blade as required to accommodate mixing of airstream. Opposed blade dampers are preferred and required for mixing 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.
8. Air filters may consist of bag or cartridge-type elements; roll filters are not acceptable. Filter design face velocity shall not exceed 500 FPM nor shall manufacturers' standard nominal ratings be exceeded. The preferred filter face section dimensions are 24 inches x 24 inches. 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.
9. Minimum 30% efficient filters shall be installed upstream of any heat recovery device.
10. Preheat coils must be steam with an integral face and bypass damper or glycol. 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 for added freeze protection. Coil vent and drain piping shall extend to outside the unit casing to vent and drain valves.

11. Cooling coil velocity shall not exceed 450 FPM at maximum future and present design conditions. For new buildings coil shall be sized for a nominal face velocity not to exceed 400 FPM 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. Coil connections, vent and drain piping shall extend to outside the unit casing. **Since this piping is not typically fully insulated they shall be all red brass construction to prevent rusting and associated leaks / failures common to steel piping.**
12. AHU fans may be vane-axial, 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. Refer to Section 15050 for vibration isolation criteria. Fan volume control may be achieved using VFDs or approved in-flight pitch adjustment on axial fans and 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.
13. 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.
14. 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.
15. Each AHU section shall be provided with drainage facilities that permit the washdown of units and contain leaks resulting from coil failures.
16. Provide factory installed and sealed wiring sleeves for all control and power wiring that penetrate the unit casing. All power wiring shall be factory installed to a single point for power source connection on the exterior of the unit.

17. For AHUs serving contaminated systems, all piping and appurtenances shall be outside of the airstream.
18. 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 0.5 percent of the supply air volume.
19. 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. The A/E shall individually review the design parameters for each field erected unit with the Office of The University Engineer.
20. 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.

E. Humidifiers for central station AHUs shall be of the dry-steam, manifold-jacketed type and be located in the AHU up-stream of the Chilled Water coil. 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.

F. 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 A/E shall ascertain that all components are serviceable.

G. The following issues shall be specifically addressed for all coil installations:

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

2. The cooling-coil face velocity must be limited to 450 FPM 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.
3. Moisture eliminators may be considered where carryover presents a problem; however, eliminators must not impede service access to the coil surface for cleaning.
4. Multiple coils are often required to provide the total capacity of individual units. The **maximum coil depth shall be 8 rows** with no more then two coils in series. Coils shall be a maximum of 10 feet long by 3 to 3 1/2 feet high and be capable of replacement without major rigging. Individual coils within a coil bank must be removable without disturbing pipe headers or other coils.
5. 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.
6. 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.
7. Even and consistent airflow across the entire coil surface is extremely important. Upstream mixing and the use of air blenders shall be carefully considered.
8. Coil bank supply and return mains or steam and condensate mains shall have manual isolation valves so that the entire unit can be drained.
9. 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.**
10. 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. Steam control valves used on integral face and bypass coils shall be controlled to the full open position when the inlet air temperature is 32 degrees or less, and to modulate in response to the setpoint temperature when the inlet air is above 32 degrees.
11. Float traps shall be used on steam coils. Trap bypass lines shall not be used; dual traps may be considered.
12. 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 modulating valves for

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 18 inches minimum. Steam coils are not to be used as preheats. If this is the only choice then the coil shall be of the face-and-by-pass type.

13. Factory-packaged units shall have offset coil pipe headers to allow individual coils to slide out of unit casings.
14. Glycol preheat coils shall be designed for parallel flow-circuiting. Glycol flow shall be maintained through the unit by a run around loop with mixing valve pump system.
15. **100% OA units design parameters are as follows: 0F EAT winter and 78F WB – 96F DB Summer.**

H. 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:

1. 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.
2. 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 without causing excessive air velocity stratification across the face of the coil. 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. Where extreme limited physical space conditions exist, the use of a carefully designed baffle plate between the fan discharge and the coil may be considered. The Contract documents should specifically address the placement of the fan with respect to the coil.

I. Fans shall be individually selected for their specific application. 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.

J. 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.

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

L. 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.

M. Specify 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. If specific sound data for the selected fan is not available, certified testing for fan sound data shall be required. The arrangement, size, class, and capacity of all fans shall be scheduled on the contract drawings for permanent records.

N. 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 25.0 hp and larger shall also be dynamically balanced in the field by the manufacturer after the installation is complete.

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

P. 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.

Q. 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 contaminated air streams, lubrication facilities shall be piped to the exterior casing wall. For supply and return air systems, lubrication facilities are not required to be piped to the equipment exterior.

R. 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.

S. 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 to 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.

T. Direct drive fans are preferred to reduce maintenance costs and improve reliability. Where factory-designed and assembled belt drives are proposed to be furnished, OSHA-approved mesh-type guards shall be provided for all belt drives, and the drives shall comply with the following:

1. 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 degrees. The motor driving 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.

C: Does this work with next motor size strategy?

2. 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.
3. Motor sheaves shall be adjustable pitch type for fans under 25 hp, 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 "initial" sheaves shall be installed on fans 25 hp and larger. All multiplex belt drive assemblies regardless of horsepower shall be fixed-pitch type. When correct “final” sheave size has been determined by Testing and Balancing Agency, furnish and install a permanent fixed-pitch sheave for motor to replace variable-pitch and “initial” motor sheaves. Turn over variable-pitch and “initial” motor sheaves to the University.
4. 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. Refer to Section 15170 for detailed motor requirements.
5. Fan sheaves shall not be smaller in diameter than 30% of the fan wheel diameter.
6. 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 _ inch or smaller bores, where set screws may be used.

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

12.0 Duct Design and Components:

A. The duct system design 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.

B. 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.

C. 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. The Project Engineer must consider potential field conditions and performance penalties in the final selection of fans.

D. 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.

E. To achieve rated fan performance, air must enter the fan uniformly over the inlet area in an axial direction without prerotation. 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.

F. 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. Compliance with NFPA Standard 90A for 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, is mandatory.

G. 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. 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.

H. 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.

I. Except as noted in Section 6.0, 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.

J. 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.

K. 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.

L. 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.

M. Air devices shall be selected to provide a uniform, quiet, and low-velocitydistribution covering the majority of the occupied area. Air devices shall not dump the air, create drafts, or generate turbulence within rooms.

N. Certain areas may require laminar flow diffusers to keep contaminants controlled below work areas until they are exhausted.

O. The terminal velocity of discharged air 24 inches from wall surfaces desirably should be less than 50 FPM. Where applications become more critical, such as for laboratories, vivariums, and treatment/procedure rooms, the terminal velocity should not exceed 30 FPM at 6 feet above floor height.

P. The University Office of Environmental Health and Radiation Safety requires review and approval of the type of laboratory hoods and hood face velocities used for each application, including the design of the supply air distribution and associated terminal velocities at hood entrances. They also will require a specific review of personnel protection issues related to transfer processes involving potentially hazardous materials, such as solvents. Usage based controls shall be utilized when applicable to conserve energy by reducing face velocities when hood is unoccupied.

Q. The minimum duct size for low pressure supply and exhaust branches is 8" x 4" (or equivalent 6" diameter). Refer to Table 10 for maximum velocity requirements.

R. 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.
Maximum Design Velocities for HVAC Systems

Element	Face Velocity Ft./Minute
DUCTWORK	
Medium Pressure Mech. Rooms/Shafts Occupied Areas	2,000 1,750

Table No. 10. Maximum Design Velocities for HVAC Systems	
Element	Face Velocity Ft./Minute
Low-pressure Mech. Rooms/Shafts Occupied Areas Terminal Outlets	1,500 1,200 500
Outdoor/Relief Air	1,500
COOLING/DEHUMIDIFYING COILS	400new 450 old systems
HEATING COILS	
Steam/Hot Water Unit	450-750
FILTERS	
Viscous Impingement	200-500
Dry Type, Extended-Surface Flat (Low Efficiency)	500
Pleated Media	500
HEPA Filters	250
LOUVERS	
Intake (free area) Exhaust (velocity across net free area)	750 1,000

S. 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.

T. 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 Element Face Velocity 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.

U. Flexible ductwork may be utilized for supply, return and exhaust air applications to connect air distribution devices to low-pressure duct mains. Flexible duct runs shall be limited to 6 feet. Flexible duct shall not be used to connect the inlets or outlets of airflow supply or exhaust terminal boxes to duct mains.

V. 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. Refer to Section 15890 duct system minimum specifications.

Table No. 11
Minimum Duct Construction Standards

Application	SMACNA Pressure Classification	Materials of Construction	Field Pressure Testing	Notes
Low-pressure Supply Ductwork	2 inches POS	Galvanized Steel	No	
Medium-pressure Supply Ductwork Upstream of Terminal Units	6 inches POS	Galvanized Steel	Yes	
Low-pressure Supply Ductwork Downstream of Terminal Units	2 inches POS	Galvanized Steel	No	
Low-Pressure Outdoor, Relief, Return Air Ductwork	2 inches POS	Galvanized Steel	No	
Medium-pressure Return Ductwork Downstream of Terminal Units	3 inches NEG	Galvanized Steel	Yes	
Low-Pressure General Exhaust Ductwork	2 inches NEG	Galvanized Steel	No	
Low-pressure Wet Process Exhaust Ductwork	2 inches NEG	Aluminum or Stainless Steel Welded	No	See Para. X
Low-pressure Potentially Hazardous Exhaust Ductwork Upstream of	2 inches NEG	Epoxy-Coated Galvanized Steel or	No	See Para. BB.

Table No. 11
Minimum Duct Construction Standards

Application	SMACNA Pressure Classification	Materials of Construction	Field Pressure Testing	Notes
Terminal Unit		Stainless		
Medium-pressure Potentially Hazardous Exhaust Ductwork Downstream of Terminal Units	CLASS I/INDUST. 6 inches NEG	Epoxy-Coated Galvanized Steel or Stainless	Yes	See Para. BB.
Special Hazard Exhaust Ductwork	3 inches NEG	Stainless Steel	Yes	

W. Those duct systems requiring field leak testing shall be tested at 100% of the duct construction rating. Leak testing shall follow general procedures (Chapter 3) and use apparatus (Chapter 5) as outlined in the SMACNA HVAC Air Duct Leakage Test Manual, Latest Edition. The A/E shall specify the allowable leakage in terms of percent of total rated cfm capacity for each duct system based on leakage allowances accounted for in airflow rate and fan selection calculations. The A/E shall specify that the allowable leakage rates for each duct section tested shall be determined by the use of Appendix C in the SMACNA HVAC Air Duct Leakage Test Manual.

X. 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.

Y. The term "hazardous 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.

Z. 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 exhaust individually and normally requires special filtration.

AA. 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.

BB. For non diluted exhaust systems (branches from fume hoods), duct to be Epoxy-Coated Galvanized or stainless steel. Manifolded exhaust systems can be galvanized where sufficient dilution has occurred.

13.0 Separation of Intakes and Exhaust

A. 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.

B. 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.

C. Separating air intake and exhaust air outlets by at least 25 feet 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.

D. An exhaust dispersion analysis performed by a qualified consultant is recommended on Laboratory Buildings to analyze and make recommendations. Under normal operating conditions, exhaust air impinging on outside air intakes of the facility or its neighbors must be sufficiently diluted to meet the air quality requirement that contaminants in intake air should be less than 1 percent of current occupational exposure limits (OELs). Furthermore, regardless of the internal dilution, the minimum external dilution (from top of stack to intake) shall be 20:1 for any building exhaust. Dilution criteria, or target concentrations shall be established to evaluate the results of the dispersion modeling. The criteria will differ with the type of source and their emission levels, can be either health or odor related. The following Table lists dilution criteria for common source types.

Table No. 12
Dilution Criteria

Source Type	Criteria Type	Dilution Criteria
Variorum	Odor	100:1
Kitchen	Odor	600:1
Laboratory Fume Hood	Health/Odor	3000:1 for a 1,000 cfm exhaust
Diesel Generators	Health/Odor	230:1 for health 4,000:1 for odor
Parking Garage	Health	4:1

E. The bottom of all outdoor intakes shall be located as high as practical but not less than 6 feet above ground level, or if installed through the roof, 3 feet above the roof level.

F. Outside air intake shall be at least 40 feet 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.

G. Fan discharge nozzles are preferred over stacks to create an acceptable discharge plume. Where stacks are used, 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:

1. Be in a vertical direction at a minimum of 10 feet above the adjacent roofline and so located with respect to opening and air intakes to avoid reentry of contaminants into any building
2. Have a discharge velocity of at least 3000 FPM.
3. Be designed so that aesthetic considerations concerning external appearance are not allowed to overcome the above requirements and the safe discharge of exhaust.

4. 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.
5. Show economic justification for their use in lieu of discharge air entrainment nozzles.

END OF SECTION