

SECTION 230000 – HVAC SYSTEMS

1.0 Types of Systems

- A. ASHRAE 90.1 Compliance: University of Pennsylvania buildings shall comply with the Commercial Energy Efficiency Requirements of ASHRAE Standard 90.1-2016. The ASHRAE 90.1-2016 compliance paths shall be followed instead of the International Energy Conservation Code (IECC) requirements as permitted by 2018 IECC Section 401.2 Application.
- B. 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.
- C. HVAC systems are usually the most significant driver of energy usage in Penn buildings. As such, designers must maintain energy efficiency as a key criteria in conformance with the University's Climate Action Plan. When integrating with existing facilities, designers should be looking for energy saving opportunities which may reach beyond the bounds of their project and bring these to the attention of the University who can decide whether or not to pursue them.
- D. 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 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.
 - 1. 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.
- 3.0 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 the central chilled water system. **See General Requirements for Engineering 010020, paragraph 24.0 Site Utilities for chilled water temperatures.**

For 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.

- 4.0 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°F rise is recommended, and in some cases a rise as high as 17°F can be economically achieved.
- 5.0 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.
- 6.0 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.
- 7.0 Air and Water Systems
- A. ASHRAE 90.1-2016 Compliance Requirements: Economizers shall be provided in accordance with the requirements of Section 6.5.1 of ASHRAE 90.1-2016, including all exceptions.
 - B. Air and water systems, when used, are generally composed of a central ventilation system and either active chilled beams or four pipe-fan coil units. Fan coil systems shall utilize both chilled water and hot water piping to each terminal fan coil unit.
 - C. Controls for these systems 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.
 - D. 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's shall be sized for a 55 F EWT.
 - E. Chilled beam systems shall be designed with a dedicated chilled beam water supply loop that provides minimum 58 degree water to the chilled beams and is isolated from campus chilled

water pressures via heat exchangers (typically plate and frame type). Controls for these systems shall sense dew points throughout the spaces to avoid condensation; additionally condensation sensors shall be provided in a selected sampling of spaces to sense any moisture on the chilled beam supply piping to the chilled beams. Operable windows shall be discouraged in buildings utilizing chilled beams.

- F. The central air systems will be utilized in conjunction with the fan coil units and/or chilled beams to maintain minimum ventilation rates.
- G. Central air systems that deliver neutral temperature air (65°F to 68°F) via energy recovery should be considered to eliminate reheat energy use.
- H. ASHRAE 90.1-2016 Compliance Requirements: Variable flow hydronic systems shall be provided in accordance with the requirements of Section 6.5.4.2 of ASHRAE 90.1-2016, including all exceptions.
- I. Secondary pumps designed for the heating or cooling piping loops shall be automatically controlled to shut off when their function is unnecessary.
- J. Variable Frequency Drives (VFDs) shall be considered for use on applicable fan and pumping systems with motors greater than 5 horsepower.

8.0 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.

9.0 HVAC System Noise Criteria

- A. Duct lining is not permitted for use in supply or return 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.
- C. 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.
 - 1. Criteria for space maximum noise levels from the HVAC systems. All levels are measured in the center of the room unless noted otherwise:
 - a. Laboratories: RC45 (N) maximum allowable HVAC noise level as measured nominally three (3) feet from fume hoods.
 - b. Laboratory Equipment Support Rooms: RC50 (N)
 - c. Animal Holding Room: RC50 (N)
 - d. Animal Procedure Room: RC50 (N)
 - e. Vivarium Support Rooms (Cagewash/Glasswash Rooms): RC65 (N)

- f. Private Office: RC35 (N)
- g. Open Office: RC40 (N)
- h. Conference Room: RC35 (N)
- i. Auditorium: RC35 (N)
- j. Classroom: RC35 (N)
- k. Mechanical Rooms: 80dBa maximum allowable HVAC system noise level as measured from the center of the room. These 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.

10.0 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.

11.0 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.

12.0 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.

13.0 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 International 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 strongly discouraged. 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. Possible exceptions may be granted to this by the University Engineering Department for neutral air systems.

14.0 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).

- 15.0 The A/E should consider the following strategies (or combination thereof) that may be used to improve the indoor air quality:
- A. 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.
 - B. Ventilation: Dilution ventilation is an effective way to control normal constant-emission sources present in buildings. Compliance with ASHRAE Standard 62 should satisfy in-door dilution ventilation requirements.
 - C. 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.
 - D. 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.).
 - E. To confirm that gaseous contaminants are not present in spaces, as well as to save energy, a system that continually senses gaseous contaminants and regulates air flow based on actual air quality, such as the Aircuity system, may be considered.
 - F. 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.
- 16.0 To the extent that it agrees with the Philadelphia (or appropriate local) Mechanical Code, ASHRAE Standard 62 (most recent additional and approved addenda) shall be used to determine ventilation rates.
- G. ASHRAE 90.1-2016 Compliance Requirements: Demand control ventilation (DCV) shall be provided in accordance with the requirements of Section 6.4.3.8 of ASHRAE 90.1-2016, including all exceptions.
 - H. 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 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 or lower than those achieved using the Standard's "Ventilation Rate Procedure".

- I. The ASHRAE Standard 62 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 known to be constant, or in systems that would not otherwise result in the economic benefits of using outdoor intake controls to track space occupancy.
- 17.0 The A/E should identify and respond to air contaminants impacting outdoor air intakes or other infiltration sites.
- A. 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.
 - B. 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 dispersion study) should be used. The possibility of snow infiltration at intakes should also be evaluated.
 - C. The possibility of snow infiltration at outside air intakes should be evaluated. Outdoor air intake rain hoods should be designed with maximum air intake velocities not to exceed 500 fpm as per ASHRAE 62. The combination of air intake louvers and intake plenums must be carefully designed to insure that snow does not penetrate the units and accumulate on filters. For mission critical 100% outside air units such as those serving vivariums, consider glycol snow melt coils.

18.0 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 shall not be recirculated. Systems shall have pressure-independent hot water terminal reheat devices (not required for neutral air systems) 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 three main parameters specified below:
 1. The amount of air required to "make-up" the air exhausted by fume hoods in the laboratory.
 2. The amount of air to meet actual design requirements of 6 air changes per hour (ACPH) or the ACPH rate set by Environmental Health and Radiation Safety Office (OEHS) Standards for each type of laboratory.
 3. 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 9 W/FT² shall be used as a minimum in design of laboratory areas (7 W/FT² for equipment, 2 W/FT² for lighting).

- B. Consider in consultation with Office of Environmental Health and Radiation Safety (OEHRs), air quality monitoring and control systems - such as Aircurity – to allow room air change rates to drop to a 4 ac/hr minimum rather than 6 ac/hr minimum with a purge mode achieving of 8 ac/hr minimum in the event of a containment incident in the space.**
- 19.0 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.
- 20.0 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 event 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.
- 21.0 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 and achieve N+1 redundancy. 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 be located out of the air stream 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.
- 22.0 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.
- 23.0 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 de-energize 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.
- 24.0 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 233100.
- 25.0 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.
- 26.0 All toilet and general use exhaust shall discharge through an exhaust system that is separate from the lab exhaust.
- 27.0 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.
- 28.0 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.
- 29.0 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. Ductwork for these systems may be constructed of stainless steel or aluminum.
- 30.0 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% Merv - 8 and 95% Merv - 14 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.
- 31.0 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.
- 32.0 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, latest edition.
- A. The A/E shall evaluate special requirements required to maintain conditions in these spaces, including, but not limited to, the following considerations:
1. Requirement for humidification/dehumidification of ventilation air.
 2. Criteria for environmental room accuracy across the entire volume of the space.
 3. Need for redundant equipment.
- B. Environmental rooms used primarily for storage functions do not require ducted ventilation air.
- 33.0 It is the intent of the University to minimize the use of humidification systems. 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.

- 34.0 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 University Engineering Department. The central supply and exhaust air system shall be sized based on the following procedures:
- A. List the individual room total air requirements accounting for hoods, sensible heat loads, and maximum air change rates.
 - B. Add approximately 5% of the system design air quantity to the total system air flow rate to account for duct leakage.
 - C. Size all AHU system components and duct mains to allow for future expansion and renovations in accordance with specific criteria furnished by The University Engineering Department.
 - D. 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.
- 35.0 All chemical storage cabinets except flammable storage cabinets shall be mechanically vented to the lab exhaust system. Flammable storage cabinets shall not be mechanically vented. Above to be confirmed on each project with the Office of Environmental Health and Radiation Safety (OEHRs).
- 36.0 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. Consider in consultation with OEHRs, an air quality monitoring and control system to allow minimum ventilation to drop to 10 ac/hr in these 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 University Engineering Department.
 - 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 and achieve N+1 redundancy. 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 air stream. 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 vivarium 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% Merv – 8 and 95% Merv – 14 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 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 vivaria 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 dust spot test efficiency.

- J. High-efficiency particulate air (HEPA) filtration of supply air may be required for animal-holding rooms housing immunosuppressed or 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.

37.0 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 usually recirculating type with ventilation rates designed to meet ASHRAE Standard 62 (current edition) and approved addenda. Designs shall include air side dry-bulb enthalpy 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:
 - 4. Off-Hour Controls as required by ASHRAE 90.1-2016 Section 6.4.3.3, including all associated exceptions.

- ~~2.~~ Ventilation System Controls as required by ASHRAE 90.1-2016 Sections 6.4.3.4 and 6.4.3.8, including all associated exceptions.
 3. Mixing plenums with minimum and maximum outdoor air dampers to accommodate minimum ventilation and economizer operations
 4. 30% efficient prefilters and 95% efficient final-filters up-stream of the coils.
 5. Preheat coils to support morning warm-up functions and large OA requirements.
 6. Draw-through chilled water coils
 7. Central AHU humidifiers only
 8. Duct distribution to terminal control devices as necessary.
 9. Return air systems shall be provided with building pressure controlled relief devices.
- D. 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.
- E. Computer or data processing facilities are commonly found in administration buildings and require special consideration.
- F. 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.
- G. 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.) sun load, and outside temperature.
- H. 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.
- 38.0 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, non-uniform 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 pre-rotation. 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.
- 39.0 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.
- 40.0 ASHRAE 90.1-2016 Compliance Requirements - Heated or Cooled Vestibules: Per Section 6.4.3.9 of 90.1-2016, heating for vestibules and for air curtains with integral heating shall include automatic controls capable of and configured to shut off the heating system when outdoor air temperatures are above 45°F. Vestibule heating and cooling systems shall be controlled by a thermostat in the vestibule capable of and configured to limit heating to a maximum of 60°F and cooling to a minimum of 85°F. See Section 6.4.3.9 of 90.1-2016 for exceptions.
- 41.0 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.

- 42.0 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.
- 43.0 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.
- 44.0 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.
- 45.0 Certain areas may require laminar flow diffusers to keep contaminants controlled below work areas until they are exhausted.
- 46.0 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, vivaria, and treatment/procedure rooms, the terminal velocity should not exceed 30 FPM at 6 feet above floor height.
- 47.0 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 or occupancy based controls shall be utilized when applicable to conserve energy by reducing face velocities when hood is unoccupied. Consider high performance fume hoods that are designed to maintain capture at reduced face velocities for hood intensive applications or where hood required air flow rates may exceed air flow required to maintain minimum room air change rates. All fume hoods shall be tested as per ASHRAE 110 (latest edition) both in the factory (meeting 8AM 0.05 criteria) and as installed in the field (meeting 4 AI 0.10 criteria).
- 48.0 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.
- 49.0 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	2,000
Occupied Areas	1,750
Low-pressure Mech. Rooms/Shafts	1,500
Occupied Areas	1,200
Terminal Outlets	500
Outdoor/Relief Air	1,500
COOLING/DEHUMIDIFYING COILS	400 new 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)	750
Exhaust (velocity across net free area)	1000

- 50.0 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.
- 50.0 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.
- 51.0 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.

52.0 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 233100 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 Terminal Unit	2 inches NEG	Epoxy-Coated Galvanized Steel or Stainless	No	See Para. BB.
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	

53.0 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.

- 54.0 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.
- 55.0 The term "hazardous exhaust" generally applies to common exhaust systems serving laboratories, fume hoods, vivaria, biosafety cabinets, etc. that by their relatively light hazard rating may be exhausted by a common exhaust system.
- 56.0 The term "special hazard" generally applies to all other exhaust systems serving BL3, BL4, radio-active hoods, etc. that by their critical nature or extreme hazard must be exhaust individually and normally requires special filtration.
- 57.0 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.
- 58.0 For non-diluted exhaust systems (branches from fume hoods), ducts shall be Epoxy-Coated Galvanized or stainless steel. Manifoldded exhaust systems can be galvanized where sufficient dilution has occurred.
- 59.0 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
Vivaria	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

- 60.0 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.
- 61.0 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.
- 62.0 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 re-entrainment 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:
- A. 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
 - B. Have a discharge velocity of at least 3000 FPM.
 - C. Be designed so that aesthetic considerations concerning external appearance are not allowed to overcome the above requirements and the safe discharge of exhaust.
 - D. 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.
 - E. Show economic justification for their use in lieu of discharge air entrainment nozzles.