

Institute of Environmental Sciences and Technology

IENT-RP-CC012.4

Contamination Control Division
Recommended Practice 012.4

Considerations in Cleanroom Design



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ABSTRACT OF KEY REVISION AREAS

WHAT IS IMPROVED

- Enhanced description about the “Integrity of Building Envelope and Interstitial Spaces to Prevent Insects/Pests Entry” in Section 4.3.12.
- Improved description on “Process-specific airflow patterns”.
- Revised language on “Wireless sensor”.
- Detail discussions about dedicated space for storing cleaning equipment, water for cleaning and waste drain, etc. were added for the “Design considerations for controlling contamination” in Section 5.9.1.
- Improved and more detail discussions on “Optimization of workflow/paths in existing cleanroom spaces”, “Design for facility disinfection” and “CFD” analysis.

WHAT IS NEW

- Added discussion on “Impacts to building pressurization control”.
- Added detail diagrams for 4 categories of airlocks: Cascading, sink, bubble and dual-compartment.
- Added “Design considerations for cleanroom entry and exit for personnel”.
- Added new discussion section on “Room pressurization strategy”.
- Detail discussion about grounding connections for wrist strap, footwear, work surfaces, metal walls and ceiling grids to avoid charging and ESD, impacts by RFI generator and ionizers, etc. were added in the “Grounding systems” in Section 5.16.
- Added more discussion on “Airflow turn-down and reset” to reflect new ISO 14644-4 (2022) standard.
- Added discussion section for “Cleanroom enclosure airtightness”.
- Added discussion on “Demand based airflow control” to reflect ISO 14644-4 (2022).
- In the Appendix C of “Cleanroom Modeling Approach”, a new terminology called “contaminant removal effectiveness” was added to reflect the new 14644-4 (2022) and 14644-16 (2019) modeling equations, this correctional factor can increase the predictability in estimation and calculation airflow rate.
- New discussion about ground filters, personnel grounding plan, ESD tester, etc. were added into the “Grounding systems” in Section 5.16.
- Many new references (articles, books and standards) were added in the Bibliography of Appendix E.

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1 SCOPE AND LIMITATIONS

1.1 Scope

This Recommended Practice (RP) makes recommendations regarding factors to consider in the design of cleanroom facilities. This discussion is limited to those environmental conditions that typically confront cleanroom designers and users.

1.2 Limitations

This RP is limited to the design of cleanroom facilities. Equipment design is not within the scope of this RP, nor does this RP address process or operational considerations, except as those considerations relate to cleanroom design.

This RP is intended to provide users with factors to consider for cleanroom design, but discussion of these factors is not intended to be all-inclusive. The specified ranges and recommended criteria are intended only to provide a framework. Specific process or other needs may dictate requirements beyond the scope of this document. This RP is not intended to supersede specific requirements established by a recognized national or international regulating body.

2 REFERENCES

The following publications were used in the preparation of this document or are considered critical to its content; their citation in no way represents an endorsement or recommendation.

The cited editions of these documents are incorporated into this RP to the extent specified herein. Subsequent revisions of these publications do not automatically supersede the cited editions. Users should investigate the applicability of revised editions of the references.

2.1 FM Global

Cleanroom Materials Flammability Test Protocol (Class 4910) October 2013

2.2 Food and Drug Administration (FDA)

Guidance for Industry: Sterile Drug Products Produced by Aseptic Processing – Current Good Manufacturing Practice. FDA (2004)

2.3 Institute of Environmental Sciences and Technology (IEST)

IEST-RP-CC001.7: HEPA and ULPA Filters

IEST-RP-CC006.3: Testing Cleanrooms

IEST-RP-CC007.4: Testing ULPA Filters

IEST-RP-CC023.2: Microorganisms in Cleanrooms

IEST-RP-CC024.1: Measuring and Reporting Vibration in Microelectronics Facilities

IEST-RP-CC031.3 Method for Characterizing Outgassed Organic Compounds from Cleanroom Materials and Components

IEST-RP-CC034.5: HEPA and ULPA Filter Leak Tests

IEST-G-CC035.1: Design Considerations for Airborne Molecular Contamination Filtration Systems in Cleanrooms and Other Controlled Environments

IEST-RP-CC052.1: Understanding, Identifying and Controlling Electrostatic Charge in Cleanrooms and Other Controlled Environments

2.4 International Code Council (ICC)

2021 International Building Code

2021 International Mechanical Code

2021 International Fire Code

2.5 International Organization for Standardization (ISO)

ISO 13408-1:2023 Aseptic processing of health care products—Part 1: General Requirements

ISO 14644-1:2015 Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness

ISO 14644-2:2015 Cleanrooms and associated controlled environments—Part 2: Specifications for testing and monitoring to prove continued compliance with ISO 14644-1

ISO/DIS 14644-4:2022 Cleanrooms and associated controlled environments—Part 4: Design, construction and start-up

ISO 14644-8:2013 Cleanrooms and associated controlled environments—Part 8: Classification of air cleanliness by chemical concentration (ACC)

ISO 14644-16:2019 Cleanrooms and associated controlled environments—Part 16: Energy efficiency in cleanrooms and separative devices

ISO 14644-12:2018, Cleanrooms and associated controlled environments—Part 12: Specifications for monitoring air cleanliness by nanoscale particle concentration

2.6 National Environmental Balancing Bureau (NEBB)

Procedural Standards for Certified Testing of Cleanrooms, 3rd ed. (2009)

2.7 National Fire Protection Association (NFPA)

NFPA 70: National Electrical Code, 2020 ed.

NFPA 318: Standard for the Protection of Semiconductor Fabrication Facilities, 2022 ed.

2.8 Semiconductor Equipment and Materials International (SEMI)

SEMI E15.1-0305 (Reapproved 1110) Specification for 300 mm Tool Load Port

SEMI E30-0520 Generic Model for Communications and Control of Manufacturing Equipment (GEM)

Z

SEMI E78-0222 Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment

SEMI E82-1106 Specification for Interbay/Intrabay AMHS SEM (IBSEM)

SEMI E84-1109 Specification for Enhanced Carrier Handoff Parallel I/O Interface

SEMI E88-0307 Specification for AMHS Storage SEM (Stocker SEM)

SEMI F21-1016 Classification of Airborne Molecular Contaminant Levels in Clean Environments

SEMI S6-0618 EHS Guideline for Exhaust Ventilation of Semiconductor Manufacturing Equipment

SEMI S12-0211E Guidelines for Equipment Decontamination

SEMI S14-0521 Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment

2.9 Sources and Addresses

FDA

Food and Drug Administration
10903 New Hampshire Avenue
Silver Spring, MD 20993
Phone: 888-463-6332
www.fda.gov

FM Global

270 Central Avenue
Johnston, RI 02919
Phone: 401-275-3000
Fax: 401-275-3029
www.fmglobal.com

ICC

International Code Council
500 New Jersey Avenue, NW
6th Floor, Washington, DC 20001
Phone: 888-422-7233
Fax: 202-783-2348
www.iccsafe.org

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ISO

International Organization for Standardization
In the US: 14644 Series documents available from IEST
1827 Walden Office Square, Suite 400
Schaumburg, IL 60173
Phone: 847-981-0100
Fax: 847-981-4130
www.ient.org
Outside the US: Documents available from representative ISO member body organization

NEBB

National Environmental Balancing Bureau
8575 Grovemont Circle
Gaithersburg, MD 20877
Phone: 301-977-3698
Fax: 301-977-9589
www.nebb.org

NFPA

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02169-7471
Phone: 617-770-3000
Fax: 617-770-0700
www.nfpa.org

SEMI

Semiconductor Equipment and Materials International
673 South Milpitas Blvd.
Milpitas, CA 95035
Phone: 408-943-6900
Fax: 408-428-9600
www.semi.org

3 TERMS AND DEFINITIONS

3.1 Definitions

The definitions of the following terms are specific to their usage within this document and may not apply to their use in other technical documents. Whenever possible, an equivalent term used in the industry or scientific communities will be mentioned along with the definition.

airborne molecular contamination (AMC)

The presence of molecular (non-particulate) species in the gas or vapor phase that may have deleterious and other contamination effects on the product, process, equipment, activity, occupant, or facility.

certification

Statement by a testing agency that a cleanroom has been tested in accordance with ISO 14644-1 and IEST-RP-CC006.3 or other applicable document and that the requirements (including cleanliness class) of these specified documents have been achieved.

class (airborne particulate)

The cleanliness class, as defined by ISO 14644-1, or 14644-12 for nanoparticles.

cleanroom

A room in which the concentration of airborne particles is controlled and that contains one or more clean zones.

electromagnetic interference (EMI)

Conducted or radiated electrical disturbances that can interfere with equipment operation; these disturbances occur anywhere in the electromagnetic spectrum, from less than 10 Hz to cosmic rays, including radio, light, and x-rays.

fan dry coil unit (FDCU)

A fan coil unit without a condensation effect. No moisture is removed from the air stream through the unit.

HEPA (high-efficiency particulate air) filters

An extended-medium, dry-type filter in a rigid frame when tested at rated airflow having a minimum particle collection efficiency of 99.97% for 0.3- μm mass median diameter particles of DOP when tested in accordance with MIL-STD-282 (IEST Type A).

NOTE: Additional information on this topic, including other filter classification, is given in IEST-RP-CC001.

latent heat

Change of enthalpy during a change of state, usually expressed in J/kg (BTU/lb.). Latent heat in substances is absorbed or rejected at a constant temperature at any pressure.

make-up air

Outdoor air introduced into a recirculated air system for the purpose of ventilation, pressurization, and replacement of exhaust air, if any.

micrometer (μm)

One millionth of a meter.

minienvironment

A localized and controlled environment created by an enclosure to isolate a product or process from the surrounding environment.

mixed-airflow cleanroom

A cleanroom in which the airflow is a mixture of unidirectional and nonunidirectional.

most-penetrating particle size (MPPS)

The particle size at which a given filter has its highest penetration (or lowest efficiency); i.e., the worst-case particle size with respect to filtration efficiency. From filtration theory, the efficiency is higher for particle sizes smaller or larger than the MPPS. In practice, the MPPS of a filter is considered to be within a measured size range typical in commercial instruments rather than at one unique particle size.

nonunidirectional-airflow cleanroom

A cleanroom in which airflows exist with a multiplicity of flow directions or multiple-pass circulation (eddies), or both.

organic vapors

Vapors containing organic molecules that originate from solid or liquid organic materials inside or outside the cleanroom due to outgassing, evaporation of solvents, combustion, chemical reactions, or other sources.

outgassing

The spontaneous release from a material of adsorbed or absorbed materials in a gaseous form.

owner

The company or organization that has the ultimate responsibility for achieving established strategic and fiscal objectives through operation of the cleanroom.

NOTE: An owner may be more concerned with cost and time parameters than a user.

particle

An object of solid or liquid composition, or both, usually between 0.001 μm and 1,000 μm in size.

radio frequency interference (RFI)

Noise that disrupts desired instrument signals. As a general rule, interference is restricted to the radio frequency spectrum of 10 kHz to 10 GHz.

recirculation air

That portion of cleanroom air that is drawn into recirculation fan or air-handling equipment through a HEPA or ULPA filter and then re-enters the cleanroom.

sensible heat

Heat associated with a change in temperature (specific heat exchange of temperature) in contrast to a heat interchange in which a change of state (latent heat) occurs.

unidirectional-airflow cleanroom

A cleanroom in which airflows have generally parallel streamlines operating in a single direction and with uniform velocity over the cross section.

ULPA (ultralow-penetration air) filter

An extended-medium, dry-type filter in a rigid frame, having a minimum particle-collection efficiency of 99.999% (i.e., a maximum particle penetration of 0.001%) for particles in the size range of 0.1 μm to 0.2 μm when tested in accordance with the methods of IEST-RP-CC007.1.

user

A product manufacturer or operational organization whose primary function is to produce a product or achieve a tactical objective in a facility.

viabiles

Living particles that are capable of performing biochemical processes and reproducing.

3.2 Abbreviations

3D

three-dimension

ACH

Air changes per hour

AFM

Atomic force microscope

AGV

Automated guided vehicle

AHU

Air-handling unit

AMC

Airborne molecular contamination

CFD

Computational fluid dynamics

dBA

A-weighted decibels

DOP

Diethyl phthalate

EHS

Environmental health and safety

EMC

Electromagnetic compatibility

EMCS

Energy management and control system

EMI

Electromagnetic interference

EOS

Electrical overstress

ESD

Electrostatic discharge (static, spark, shock)

FA

Factory automation

Z

FDCU

Fan dry coil unit

FFU

Fan-filter unit

fpm

Feet per minute

HPM

Hazardous production material

HVAC

Heating, ventilating, and air conditioning

IBC

International Building Code

I/O

Input/output

LLD

Liquid leak detection

MAH

Make-up air handler (or handling unit)

MEMS

Microelectromechanical systems

MERV

Minimum efficiency reporting value

MPPS

Most-penetrating particle size

NC

Noise criterion

OA

Outside air

OHT

Overhead hoist transport

Pa

Pascals

PTFE

Polytetrafluoroethylene

PVA

Polyvinyl alcohol

RAH

Recirculation air handler

RFI

Radio frequency interference

RGV

Rail guided vehicle

RH

Relative humidity (in percentages)

RMS

Root mean square

RO

Reverse osmosis

SDS

International Safety Data Sheet

SEM

Scanning electron microscope

SPM

Scanning probe microscope

TEM

Transmission electron microscope

UPS

Uninterruptible power supply

w.c.

Water column

WIP

Work in process

4 PLANNING AND PROGRAMMING PROCEDURES

The planning of cleanroom project requirements should incorporate all elements of the project typically developed by a project designer in conjunction with the user and stakeholders such as the owner. The project planning should define the critical processes and specify the support requirements of the user and the plant and facility organization.

4.1 Mission Statement

A cleanroom project should begin with the preparation of a mission statement that describes the goals of the project, outlines the schedule, and identifies who is responsible for the project within the user organization.

4.2 Goals and Strategy

To facilitate the interpretation of the mission statement, the owner should prepare a statement of requirements to accompany the mission statement. The statement of requirements should specify goals for the technical function, the form, the budget, and the schedule.

4.3 Collection and Analysis of Facts

Information should be collected and analyzed on the following cleanroom design issues and considerations:

4.3.1 Critical equipment process and support requirements

The first step in determining the needs of a cleanroom project is to identify the occupancies, equipment, and processes for which the cleanroom is being constructed.

- a) A listing should be compiled of all planned occupancies, equipment and processes to be expected in the cleanroom, and a matrix should be created listing requirements for each process and piece of equipment. This matrix should define the processes in as much detail as possible and identify all requirements related to chemicals, gases, and liquids. Power, temperature, humidity, exhaust, vacuum, vibration, electromagnetic interference (EMI), radio frequency interference (RFI), size, shielding, and waste removal requirements should also be identified.
- b) It is preferable to provide peak demand and normal usage requirements for each service identified within the matrix, rather than to apply diversity factors in initial planning stages. Diversity factors may be applied later as a result of discussions between the design professional and user.

4.3.2 Contamination control guidelines

The needs of each process should be categorized by the type of contamination control that affects the critical function of that process. Such categorization may vary from project to project and from process to process. As a general rule, a defined hierarchy of cleanliness should be specified for a project, rather than a single contamination control class established for all spaces. Spaces should not be categorized into classes defined by ISO 14644-1 or other air cleanliness specifications until such a classification is fully justified.

Categories of contaminants include the following:

- Biological—Biological properties of a contaminant that adversely affect the process or product.
- Energy—See Table 1.
- Molecular—Groups of atoms possessing chemical, mechanical, moisture, or biological characteristics detrimental to the product, process, metrology, or people.
- Particle—Size-related contamination, in which the process or product is adversely affected as a result of the size of the contaminant.

Table 1. Categories of contaminants.

Contaminants	Magnitude	Effects	Examples	Remedy
PARTICLE	$10^{-3} \mu\text{m}$ to $10^3 \mu\text{m}$	Chemical	Reactions of ionic species such as ammonium salt; corrosion	Mechanical filtration, scrubbers, or both
		Mechanical	Optical defects, scratches, stiction for MEMS ¹ , plugging for microfluidics, filter clogging	Mechanical filtration
		Electrical	Electrical shorts, open circuits, leakage currents	Mechanical filtration
		Biological/Microbial ¹	Bacteria, molds, yeasts, viruses	Mechanical filtration decontamination; UV or chemical sterilization
MOLECULAR	$<10^{-3} \mu\text{m}$	Chemical	Ionic species, corrosion, haze, doping, electrical defects, metrology errors, lithography errors, film defects, delamination, air ionizers (deposits, imbalance, particulation, increased maintenance)	Physical/chemical adsorption, isolation in boxes, minienvironments, use of cluster tools without air exposure, inert gas purges, source reduction, better abatement
		Mechanical	Film deposition, adsorbed molecules, moisture effects on process, delamination, light scattering, corrosion	Better scrubbing of exhaust, AMC filtration, clean purges for critical environments

Contaminants	Magnitude	Effects	Examples	Remedy
ENERGY	NA			Ref: IEST-RP-CC022
EMC ² design		Electrical	Sensitivity to RFI, EMI	Shielding, grounding, circuit
EMI ³ control		Electrical	Software lockup, false signals	Shielding, grounding, source control
RFI ⁴ control		Electrical	Communication failures, false signals, lockup	Shielding, grounding, source control
Electrostatic Control ⁵		Electrical	Software lockup, automation failures, mask defects, fire, open circuits, particles, hard failures, soft failures	Grounding, ionization, dissipative materials
TEMPERATURE	Process specifications and regulations	Mechanical	Thermal expansion or contraction, dimensional stability	HVAC control
HUMIDITY	Process specifications and regulations	Biological	Microbial growth rate, corrosion, haze	HVAC control
LIGHT				
INTENSITY	Process specifications and regulations	Comfort and Safety	Fatigue/color/accuracy/glare	Fixture design and selection
WAVELENGTH	Process specifications and regulations	Physical/ Chemical	Photoresist UV exposure	Shield, filter
SOUND				
SOUND PRESSURE	Process specifications and regulations	Mechanical	Affects lithography, SEM, AFM, metrology	Source reduction, isolation
FREQUENCY SPECTRUM	Process specifications and regulations	Mechanical		
VIBRATION	Process specifications and regulations	Mechanical	Affects lithography, SEM, AFM, metrology	Source reduction, isolation
¹ See RP-23 for more information ² Electromagnetic compatibility ³ Electromagnetic interference ⁴ Radio frequency interference ⁵ See RP-52 for more information				

4.3.3 Life safety

a) The cleanroom may be the site of exotic chemistries or other processes that may affect safety. Because personnel safety is critical, the following design features should be considered in the development of cleanroom life safety systems. A good life safety reference is NFPA 318.

1. The controlled purge of air circulation zones separated by physical barriers to permit individual control
2. Control of the dispersion of hazardous gases and vapors by means of zone separation

3. Storage of toxic or flammable materials outside the process floor
 4. Hand delivery or bulk distribution of chemicals from outside the process floor, under controlled conditions, often in double-walled-pipe or double-contained delivery systems
 5. A minimum exit distance from the process space to a fire protected area, as recommended by codes
 6. Maximum contiguous floor area, as limited by codes
 7. The isolation of hazardous materials from personnel
- b) In the interest of safety, cleanroom design should follow specific code requirements. The matrix of support requirements, as identified in section 4.3.1, should be carefully reviewed to identify the kinds and quantities of hazardous materials that may be present. The insurance company and internal safety organizations employed by the owner should be contacted to evaluate life safety issues that may be specific to the site.
- c) Care should be taken to coordinate life safety and cleanroom operation requirements. Because pressurization control is critical to the cleanroom, automatic shutdown of the air-handling systems without other remedy might damage cleanroom integrity in preventing migration of contaminants from outside into the cleanroom. Backup power for critical systems, including toxic compound abatement or scrubbers, is recommended.
- d) Proper exit paths should be easily identifiable to those who may be exiting areas isolated from the exterior.

4.3.4 Environmental issues

- a) The internal environmental, biological, chemical, electrostatic, temperature, humidity, and vibration requirements of each process should be identified and a determination made as to whether these criteria are required by the process or have been arbitrarily established by personnel.
- b) The effect of the cleanroom on the external environment should be thoroughly considered. While the cleanroom is required to protect a process from contamination, the process itself may require elements or create waste products that are environmental contaminants. The cleanroom design process should identify and classify all potential environmental contaminants, such as gaseous, liquid, or solid wastes. The type and quantities of each should be evaluated against regulatory requirements to verify compliance.

A secondary containment strategy, such as the use of chemical-resistant coatings and membranes, should be developed to prevent ground water contamination.

- c) Just as the effect of the cleanroom on the external environment should be considered, so should the external environment effect on the cleanroom be considered. In particular, the placement of air intakes and exhaust will significantly influence the design of the heating, ventilating, and air conditioning (HVAC) system. Care must be taken to place exhausts from the cleanroom (often containing hazardous materials in minute quantities as well as odors) such that the effluent is not re-entrained by the cleanroom make-up air handler (MAH), or by adjacent building air intakes. Make-up air intake locations must also be carefully considered to avoid as much as possible the entrainment of known contaminants such as vehicle exhausts from loading areas or parking areas.

An exterior airflow study is recommended for new construction. Exterior air flow studies, also described as wind-wake analyses or exhaust dispersion analyses, should include prevailing wind conditions and modeling of existing structures including exhaust sources and air intakes. Studies often use computational fluid dynamics (CFD) or traditional wind tunnel models to provide recommendations for exhaust dispersion and optimal locations for fresh air intake.

4.3.5 Personnel requirements and public relations

- a) The cleanroom design should provide an ergonomic, aesthetic working environment. Plans for the flow of personnel into areas of increasing levels of cleanliness should accommodate gowning operations, use of rest rooms, eating and break areas, and the number of personnel requiring access to the cleanroom areas.
- b) The external design should accommodate the actual and perceived effects of the cleanroom design on non-cleanroom personnel and on neighbors in surrounding properties.

- c) If preferred, observation windows can be placed on interior walls adjacent to an environmentally controlled corridor where visitors can view the cleanroom operation without the need to access the cleanroom.

4.3.6 Critical material flow

Efficient cleanroom operation demands a significant initial effort to determine functional interdependencies, adjacencies, and the flow of personnel and material traffic. The following should be considered:

- a) Product flow through a single process area
- b) Product flow between process operations
- c) Communication between groups inside and outside the process areas
- d) Raw material flow to the process operations
- e) Personnel movement within process areas
- f) Personnel movement between process and non-process areas
- g) Access to comfort facilities and drinking-water fountain
- h) Hazardous material flow to and from the process functions
- i) Delivery routes of heavy materials, process equipment, and maintenance equipment

4.3.7 Site selection and service requirements

To evaluate relevant existing conditions, cleanroom projects may require the development of baseline information about the site in addition to normal demographic studies.

- a) To establish a baseline for future site monitoring systems, environmental studies may be required to identify existing ground water and soil toxicity if ground water is the source for domestic or process uses with necessary treatments. Further monitoring of city water supply and ambient air quality may be required if the process is sensitive for these qualities of ground water and soil toxicity.
- b) Vibration baseline testing may be required to establish the ambient vibration level and to determine the acceptability of the vibration level to the process.
- c) Proximity to highways, railways, airports, dumps, sewer plants, agriculture, power plants, mining, paper mills, chemical industries, refineries, semiconductor plants, oceans, inland seas, and other sources of vibration and air pollutants should be considered.
- d) Sites should be evaluated for appropriate zoning and for compatibility with neighboring properties, especially residential areas, schools, healthcare facilities, and senior centers.
- e) Cleanrooms that incorporate a production process may benefit from financial incentives provided by local tax laws and government regulations.
- f) Power and energy availability and reliability should be considered.

4.3.8 Security and access control

- a) Security measures may be required in cleanroom facilities to protect against access by unauthorized personnel. Many cleanroom facilities also require the security of proprietary technical information.
- b) Protocols to control access to a cleanroom usually are layered in the same manner as the hierarchy created for a cleanliness protocol. Such protocols provide security and limit the number of people in a cleanroom.

4.3.9 Government regulations

- a) Codes that govern the construction and operation of cleanrooms are often adopted and amended by local agencies. All relevant codes should be clearly identified.

- b) Most local agencies have enacted air and water quality regulations, as well as specific restraints on the activities that may occur in specified planning and zoning areas.
- c) Most regulatory environmental control agencies have enacted facility operating mandates and reporting requirements that should be considered early in the project.
- d) Relevant regulations may vary from country to country and from locality to locality. It is recommended that unless local regulations that address the particular needs of cleanroom facilities can be identified, the intent of the International Building Code (IBC) and associated documents be viewed as minimum requirements, regardless of the location in which the facility is constructed.

4.3.10 Fire protection

Normal cleanroom operations involve moving a large, continuous volume of clean, filtered air. Materials and chemicals used in cleanroom processes may be flammable and may be a source of combustion or fuel. Unchecked, a fire may rapidly spread throughout the facility. A careful analysis of the proposed facility layout and the chemicals to be used in the process will help establish effective fire protection.

a) Designing for fire prevention

1. Non-combustible construction materials should be used in HEPA and ULPA filters, ductwork, and wet benches (i.e., UL Class 1 or Class 2 rated materials), FM Global-approved materials, or equivalent. See *Cleanroom Materials Flammability Test Protocol (Class 4910)* for listed materials.
2. Recirculating exhaust air should be avoided.
3. Chemical exhaust ductwork should be smooth and allowed to drain in the case of condensation.
4. Exhaust systems should be designed to adequately dilute the constituents of flammable vapors.
5. Proper location and storage of flammable gases and chemicals, including appropriate segregation of incompatible materials, should be provided.
6. Proper location for chemical mixing areas should be provided.

b) Water sprinklers

Automated deluge water sprinklers should be installed according to local regulations in areas that have a fire risk. Sprinkler heads should be located so installed equipment does not interfere with the water spray coverage. Drains should be provided in the vicinity to avoid flooding of adjacent areas if a sprinkler is activated. The drains should have p-traps or water seal mechanisms to keep waste stream gases or sewer gases from entering the room. In some instances, p-traps can dry out and allow sewer or other gases to enter the cleanroom, posing contamination risks and health risks. Therefore, 1 liter of water should be poured into p-traps at least quarterly, and more often if needed. Sprinkler heads that may be exposed to corrosive atmospheres should be coated to prevent corrosion.

Sprinklers should be installed in the following locations:

1. Inside down-flow air streams
2. Inside flammable gas cylinder storage areas
3. Inside storage areas for pyrophoric and directed at the tanks of pyrophoric chemicals
4. Inside plenum and interstitial spaces above cleanrooms
5. Inside any combustible ductwork
6. Inside any pass-throughs used to convey combustible chemicals

c) Additional fire-suppression methods

If water-reactive or highly sensitive equipment is present, other fire suppression methods may be needed, such as carbon dioxide, dry chemicals, or others for suppressing organometallic compound fires.

d) Detectors and alarms

1. Smoke detectors should be located inside return air-stream ductwork and in the vicinity of pyrophoric chemical tanks and should be audibly distinctive from other alarms in the cleanroom.
 2. Automatic fire suppression systems should activate audible fire alarms in the cleanroom that sound different from other alarms or signals used in the cleanroom.
 3. Alarm systems should be able to be bypassed or disabled during cleanroom performance testing or certification.
- e) Inhibiting fire propagation
1. Firewalls should separate the cleanroom from other areas and should provide the appropriate fire resistance rating according to the applicable code. Access holes through firewalls may require fire doors to meet building code requirements.
 2. Areas that share air handlers should be designed to minimize the chance of cross-contamination by smoke propagation during a fire. For multilevel facilities (e.g., cleanrooms with subfabs and plenums), complete air-stream segregation should be considered at every level, not just the fab floor. Each level should be subdivided into smoke zones in accordance with code requirements.
- f) Non-combustible materials for furnishings and equipment
1. Stainless steel or other metals are recommended for use in the cleanroom based on compatibility with the products or processes.
 2. When plastics are required for workstations, cabinets, or other components within the cleanroom, these components should be constructed of flame-retardant plastics.
 3. Some polymers contain flame-retardant additives that may outgas and affect sensitive processes. For example, organophosphorus flame retardants may outgas into the air, land on products, and affect electrical properties of silicon wafers.

4.3.11 Redundancy

Redundancy in critical equipment or systems may be justifiable in cleanroom projects to ensure continuous operation and maintain room conditions. Costs associated with redundant systems should be evaluated in relation to the risk of lost product and cleanroom restart and certification costs. The designer and owner should establish a clear understanding of the systems and the respective levels of redundancy required to satisfy operational goals.

When considering a cleanroom installation, three key elements to redundancy should be addressed: reliability, flexibility, and serviceability.

a) Reliability

Because of market demands that require continuous production, some operations no longer include maintenance periods in production plans. Therefore, critical systems should be evaluated to provide continuous operations for the life of the manufacturing processes. Table 2 describes redundancy levels ranging from no extra capacity to fully functional duplicate production and distribution systems.

Table 2. Redundancy levels.

Level 0 Redundancy (R0)	No capacity provided above the maximum demand placed on the systems. No provisions for future additions or expansion.
Level 1 Redundancy (R1)	No capacity provided above the maximum demand placed on the system. Provisions made for additional equipment installation without operational interruptions.
Level 2 Redundancy (R2)	Capacity of major components within critical systems may be lost without affecting the ability of the system to supply the maximum demand. • Restoration of system is manual. • No additional equipment is required to be installed at time of failure. • System design does not facilitate the removal or replacement of failed components. • Redundant components may not be used to perform planned maintenance.
Level 3 Redundancy (R3)	Capacity of major components within critical systems may be lost without affecting the ability of the system to supply the maximum demand. • Restoration of system is automatic. • No additional equipment is required to be installed at time of failure. • System design does not facilitate the removal or replacement of failed components. • Redundant components may not be used to perform planned maintenance.
Level 4 Redundancy (R4)	Capacity of major components within critical systems may be lost without affecting the ability of the system to supply the maximum demand. • Restoration of system is manual. • No additional equipment is required to be installed at time of failure. • System design does not facilitate the removal or replacement of failed component(s). • Redundant components may be used to perform planned maintenance.
Level 5 Redundancy (R5)	Capacity of major components within critical systems may be lost without affecting the ability of the system to supply the maximum demand. • Restoration of system is automatic. • No additional equipment is required to be installed at time of failure. • System design facilitates the removal or replacement of failed components. • Redundant components may be used to perform planned maintenance.

b) Flexibility

Flexibility to facilitate future expansion and change should be considered in the design of cleanroom projects. The following is a partial list of features that may enhance cleanroom flexibility:

- Addition of air recirculation units to accommodate future increases of airflow rate, or addition of AMC filters if needed.
- Zone design that will facilitate the rearrangement of any zone with minimal interruption of adjacent zones or the total system.
- Load-sharing ability in case of equipment malfunction.
- Demountable walls to permit rearrangement of the floor layout.
- Location of services distribution near equipment to facilitate access.
- Location of service mains outside the process floor and placement of branch connections to facilitate process line modification.
- Location of support services outside the process floor.

c) Serviceability

Maintenance of equipment and support facilities may be improved by providing easy access for repair and replacement. Mechanical and electrical support systems should be designed and installed to allow routine

maintenance, repair, and replacement without major interruptions to normal operations. Major service equipment should be located outside the process floor footprint. The requirements of cleanroom facilities for support maintenance are often underestimated. A separate cleanroom facility may be required. In many cases, support equipment that does not need to be in the expensive cleanroom space can be located in a subfab, or in some cases in a central utility room or building that may supply one or more cleanrooms.

4.3.12 Integrity of Building Envelope and Interstitial Spaces to Prevent Insects/Pests Entry

The cleanliness of pharmaceutical, semiconductor, and other critical cleanroom applications can be seriously compromised by microbial and other residues left by insects (such as spiders, ants, or bees), rodents, and birds or other pests that may find a pathway into cleanrooms, support areas, and interstitial areas. Unlike particles, such pests have the ability to move against pressurized airflow.

Architectural plans for new and renovated buildings that contain cleanrooms should include proper sealing designs and techniques to prevent pests from entering the buildings. Penetrations that affect the air-tightness of the building—such as entrance of pipes, vents, ductwork, foundations, and siding as well as cracks due to settling—should be addressed. A whole-building blower-door test for air-tightness should be performed. Infrared cameras can also be used to detect and verify both designed-in and unknown air leakage.

Other effective preventive measures can be employed to further reduce the risk of pests entering a facility, as follows:

- Use of non-shrinking sealing caulks and other sealing materials during construction as noted on architectural plans. Caulks with low outgassing may be required, especially for semiconductor, disk drive, or laser factories. Silicones should be avoided, and urethanes should be verified per IEST-RP-CC031.3 not to outgas detrimental organophosphate fire retardants.
- The entire building that contains a cleanroom or cleanrooms should be designed with a slightly positive pressure of at least 0.01 in. of water column (2.5 Pa) relative to outside atmospheric conditions.
- Fine-mesh bird and insect screens on air-handling units (AHUs), downstream of intake louvers.
- Fine-mesh bird and insect screens at upstream of exhaust fan outlets, termination ducts or units.
- Structural partitions in large or multiple connecting interstitial spaces to minimize migration of pests that breach the system.
- Self-closing exterior doors for entryways and loading docks.
- Screens on other openings such as windows, penthouses, and shafts that must remain open for ventilation or other maintenance.

Traditional pest control such as spraying of pesticide chemicals may produce contamination that may affect products produced within a cleanroom, which can have serious repercussions for products designed for human consumption. Therefore, the risk of an occurrence and possible remediation plans should be discussed during the design phase so possible problems can be addressed in a timely way. These plans should include the following:

- Frequent inspection of roofs, foundations, exteriors, interstitial areas, and support areas
- Routine cleaning and vacuuming of interstitial, support, and service areas
- Baiting and trapping

4.3.13 Effects on building pressurization control

Factors below can influence the performance of the cleanrooms' pressurization control:

- a) The frequency and duration of opening doors can influence the cleanroom airflow by causing a pressure differential loss beyond the air-handler capacity, this phenomenon may affect the capability of the cleanroom to maintain sufficient air pressures at relevant rooms.
- b) If an outside door (such as shipping/receiving) is left open, a large shop space or hallway that may be used as the "reference point" for other rooms under various pressures may be affected.

- c) Intermittent or periodic (cycling) of equipment exhaust may influence a cleanroom's pressure stability by causing a depressurization beyond the air-handler capacity.
- d) Use of "pass-through" devices for material transfer can help maintain proper cleanroom pressurization and directional airflow.
- e) The use of airlocks for personnel movement can help maintain proper cleanroom pressurization and directional airflow. See section 5.7.3 Design parameters in pressure specifications.

4.4 Alteration of Existing Facilities

Alteration of an existing facility requires strategies that are different from new construction. Alterations, in terms of improvement, renovation or retrofit, and the like, are generally undertaken to increase production capacity, add new functionality, or upgrade processing technologies. Replacing equipment in a cleanroom may require extraordinary measures to enter the cleanroom, and alterations may be necessary for proper installation.

4.4.1 Planning involvement

Because of the complexity of an alteration, every functional group operating in the cleanroom should be involved in the planning. Each discipline should supply critical information in the planning stages to enable successful completion of the project and uneventful continuation of the processes. Personnel representing the following groups should be involved from planning stages to project completion:

- a) Production and operations
- b) Process engineering
- c) Process equipment engineering
- d) Contamination control
- e) Quality assurance
- f) Safety
- g) Facilities
- h) Contractors

4.4.2 Site preparation

A thorough analysis of the project should be undertaken to determine precisely which parts of the cleanroom will be affected by the alteration. A plan should be developed to minimize the generation or dispersion of contamination and to implement the subsequent cleanup of affected areas. Considerations include the following:

- a) Cleanroom entry areas and pass-throughs
- b) Cleanroom hallways or passages leading to the construction area
- c) Destination or location of construction activity
- d) Chases or tool cores
- e) Air handling systems

In cases involving equipment that is larger than existing pass-throughs, a penetration through existing cleanroom walls should be planned. A temporary airlock should be devised and constructed to allow for demolition (if necessary) of the existing wall and associated cleanup. The conditions (e.g., particle, temperature, and humidity control) of the cleanroom should be considered when designing this airlock. After the equipment has been inserted, cleaned, and transported into the cleanroom, the cleanroom wall can be rebuilt and the temporary airlock removed. The wall should be reconstructed in a way that allows future entry or exit of large equipment without major demolition.

4.4.3 Preparation of equipment and materials

Equipment and materials entering an established cleanroom should be properly pre-cleaned in appropriate airlocks before cleanroom entry, according to protocols established for the operational cleanroom. Materials that will become part of the finished facility (e.g., wall panels, flooring, finishes) should be compatible with the processes and products produced in that cleanroom. Each chemical supply (e.g., glues, sealants, fluxes) should have the appropriate safety data sheets (SDS) on file at the site and should be allowed to thoroughly cure or be thoroughly cleaned before making the work area operational, either between sessions or at the end of the project. Gowning and behavior protocols should be strictly enforced.

4.4.4 At-rest conditions

If possible, alterations should be performed between periods of operational hours such as off-shift hours, weekends, or during extended general facility shutdowns. Arrangements should be made to remove sensitive products that may be in the path of incoming equipment or materials or near the alteration site. A barrier should be constructed around the alteration site to prevent migration of particle contamination into adjacent cleanroom space. An air quality sampling plan should be instituted in adjacent areas. Air supplies should be minimized in the work area to avoid emission of particles from the work areas. Exhausts or air returns should be left open if allowed. Demolition or waste materials generated by the activity should be carefully controlled, packaged, and removed from the cleanroom at the end of each construction workday. The entire work area should be carefully cleaned and normal clean airflows restored at the end of construction. Particle measurements should be taken before removing walls. Before removing the temporary walls, certification of the renovated cleanroom may be necessary if the cleanroom has been substantially changed.

4.4.5 Operational conditions

Many cleanrooms operate in a continuous mode (24 hours a day, 7 days a week) and cannot be shut down to install equipment or alter facilities. If normal operations must coexist with installation or alteration activities, the area under activity should be carefully and completely isolated from the surrounding area. This is accomplished as described in section 4.4.4 but with greater attention to detail. Risks to exposed product should be carefully assessed and a monitoring program implemented to prevent contamination generated in the work area from migrating into the surrounding cleanroom. Pressurization, entrance and exit procedures, and waste removal are critical concerns. Chemicals used in the alteration activities should be considered to avoid adverse effects on the products or processes in the cleanroom or nearby areas sharing the air streams. Frequent particle checks should be performed and corrective actions taken immediately when readings approach upper operational limits. Note that HEPA filters do not remove molecular species that may contaminate other areas despite low particle counts in those areas.

4.5 Energy Efficiency

Cleanroom HVAC systems used in the semiconductor, pharmaceutical, and healthcare industries are very energy intensive, requiring large volumes of cleaned air to remove or dilute contaminants for satisfactory operations. A well-designed cleanroom is expected to achieve two goals: effective contamination control and high energy efficiency. Figures 1 and 2 (Tschudi and Xu 2003) illustrate relative energy use of various components in typical cleanroom facilities of different classes, with the environmental systems accounting for approximately half of the total cleanroom energy use. Energy use varies significantly with system types, system design, cleanroom functions, cleanliness requirements, and requirements for the control of critical parameters such as temperature and humidity. The main factors that determine cleanroom energy use are cleanroom airflow rates and types and operational efficiency of the HVAC systems. However, there is a tendency to design excessive airflow rates into cleanroom HVAC systems, because of factors such as design conservatism, lack of thorough understanding of airflow requirements, concerns about cleanliness reliability, and potential design and operational liabilities.

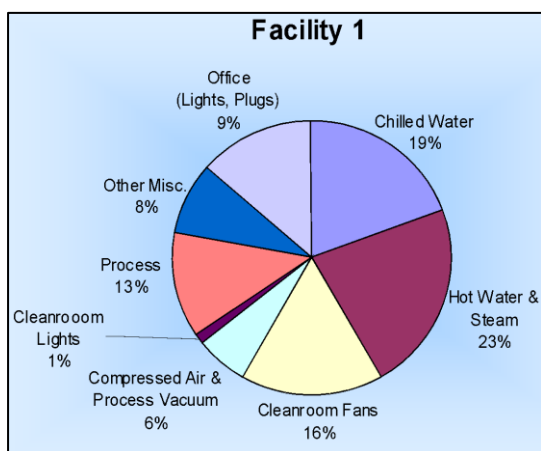


Figure 1. Cleanroom energy end use (Example 1).

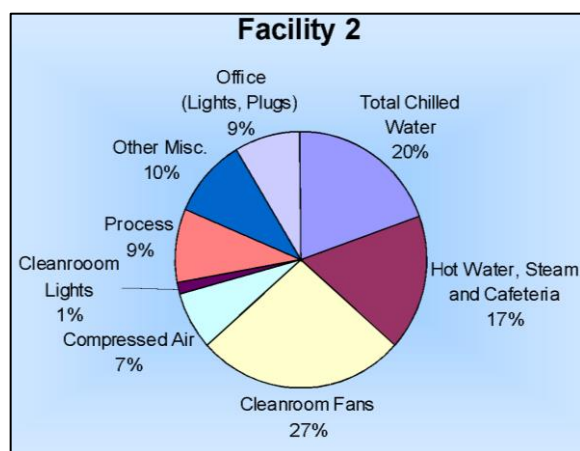


Figure 2. Cleanroom energy end use (Example 2).

In particular, supplies of cleanroom airflows specified by cleanliness class have an effect on long-term energy use. Typical airflow ranges are provided in 5.2.3, but in certain cases it may be possible to design a system that supplies less airflow while meeting cleanliness requirements in the actual operation, significantly reducing the fan energy use in the recirculation system (see Appendix D for a discussion).

In summary, improving energy efficiency in cleanrooms could contribute to significant savings in the initial costs of the facilities as well as operation and maintenance costs. In addition to direct cost reductions in cleanroom investment and operation, energy-efficient designs can reduce maintenance costs, increase power reliability, improve time-to-market in cleanroom production, and improve environmental quality. Companies that use energy efficiency to lower costs and increase productivity can gain a competitive advantage and achieve a higher return on investment. In addition, energy-efficient cleanroom systems conserve energy and natural resources, heightening the company's reputation as an environmentally conscious leader in the community and industry.

Factors determining air system efficiency include cleanroom activities (e.g., product, process, occupancy, cleanliness class), system types and layouts, airflow rates, airflow patterns and distribution, particle size, particle transport rate, spatial pressure control, and system equipment and components such as filters, air pathways, and duct sizes (see Table 3).

Table 3. Key considerations for improving energy efficiency in cleanrooms.

Considerations	Concepts and actions
Process heat load	
Nameplate data	Understand nameplate data, which is nominal load information, vs. actual equipment performance
Electric load	Understand actual load vs. design conservatism Adopt efficient process equipment, transformer, and UPS
Efficient operation	Understand efficiency of partial load and consider future expansion
Contamination control	
Cleanliness classification	Understand and define the need for contamination control Understand and define recirculation air change and airflow rate Optimize fan speeds Define filter coverage Define filtration efficiency Define airflow uniformity requirements Analyze location impact of recirculation and exhaust Identify source of contamination

Considerations	Concepts and actions
Make-up and exhaust requirements	- Define and optimize airflow rates - Assess discharge limits and apply source controls or scrubbers to meet safety and regulatory requirements - Ensure exhaust air to meet legal limits - Consider using make-up air scrubbers or localized AMC removal systems for most critical processes to reduce effluent levels
Optimal environmental requirements	- Optimize humidity - Optimize temperature - Define particle concentration - Optimize pressure - Optimize cascading
Recirculation air systems	
Optimal efficiency	- Adopt performance metrics such as electric power demand (Watts) per airflow rate - Component efficiency (e.g., fan-filter units)
Space management	Layout and adjacency to primary cleanrooms
Optimal airflows	- Right size - Optimize air management design and airflow pattern - Define ranges of air change and speed targets - Aim at low pressure drop air handlers and system uniformity
Optimal filtration	- Select prefilters and cleanroom filter media with the lowest initial resistance and highest loading capacity. - Define filtration efficiency - Provide demand filtration control of particles - Control with occupancy and scheduling - Use low-pressure drop ductwork distribution design
Physical parameters	- Define humidification range - Define temperature range - Specify pressure differential and control
Make-up and exhaust systems	
Optimal efficiency	- Right sizing - Adjacency - Duct layout - Optimal placement, sizing, and filtration - Duct integrity - Component efficiency - Variable speed drive
Optimal airflows	- Code requirements - Process diversification - Heat exhaust - Room and building pressurization control - Low pressure drop - Layout of ducts - Optimal airflow speeds
Chilled water and cooling tower water systems	
Optimal system efficiency	- Chilled water supply and return temperatures - Cooling tower supply and return temperatures - Air-side and water-side "free cooling" - Performance target for chillers and systems - Control for partial load operation - Efficient pumping - Variable speed drive

Considerations	Concepts and actions
	Adjacency and layout of major equipment Low pressure drop water system
Process cooling	Alternatives to process refrigeration Non-compressive cooling
Electrical systems	
Optimal power efficiency	Higher voltage Power factor Efficient power supplies Efficient lighting and controls Efficient UPS Efficient motors
Optimal process load	Efficient process equipment Right-size Coordination with mechanical systems
Control systems	
Protocol	Open
Monitoring	Adequate capability Internet capability EMCS systems for power and airflow
Environmental control	Humidity Temperature Airflow Particle Pressure AMC – if needed

4.6 Ergonomics

Personnel working in cleanrooms may perform repetitive motions that, over time, may result in cumulative trauma disorders and chronic muscular or nerve damage. This health and safety problem may be minimized by avoiding conditions that cause people to repetitively reach and stretch beyond normal ergonomic ranges and by providing sufficient working space. The cleanroom design should avoid these situations because ergonomic problems are difficult and costly to correct after construction is completed and the cleanroom is operational.

Cleanrooms are generally designed with advance knowledge of the equipment to be used in the process. The floor plan precisely locates process equipment to allow for electrical, plumbing, and ventilation facilities. However, a floor plan does not provide the three-dimensional view necessary to identify potential ergonomic hazards. The details of each piece of equipment should be reviewed so that special features can be added to the cleanroom during the design phase. The following conditions should be considered:

a) Vertical working surfaces

Displays, keyboards, and controls should be placed within normal reach limits. Placement of such items above or below normal work height may create ergonomic hazards and should be avoided.

b) Horizontal working surfaces

Work surfaces, loading, and processing stations should be placed at heights that are within normal reach limits. Stacking multiple workstations (such as diffusion furnaces) requiring access by ladders should be avoided if possible.

c) Working clearances

Spaces between equipment should follow guidelines specified by manufacturers. The space surrounding service areas should be free from obstructions that may prevent service personnel from properly accessing the equipment.

4.7 Constructability

- a) Coordination of the support systems required for a cleanroom should be carefully considered during the design process. The most important components of a cleanroom are often the last to be installed. Mechanical and electrical systems should be routed in a manner that will facilitate proper installation of the process support systems later in the project.
- b) Cleanrooms should be constructed under clean conditions. Normal construction practices do not meet cleanliness requirements. A construction protocol should be developed that defines specific levels of cleanliness for each level of construction (see section 6). The construction protocol should be implemented at appropriate times. An overly restrictive construction protocol may dramatically increase the cost of construction and delay the project, but failure to apply a restrictive and verifiable construction protocol may result in contamination that may prevent the cleanroom from achieving its intended goals.
- c) Construction activities should be carefully sequenced to meet clean construction requirements. Some construction activities may conflict with the cleanliness protocols governing cleanroom construction. For example, drywall should not be installed after a cleanroom has achieved clean levels, and HEPA filtration should not be installed while general construction is still underway.
- d) The cleanroom construction schedule typically is critical. Because cleanrooms are often required to support new technologies or products, there may be time pressures to market the product or use the technology. Therefore, it is not unusual for construction to take place while technical and process requirements are changing.

4.8 Determination of Needs

The design process should clearly identify the needs of the project to avoid overdesigning. Slight variations in the quality level of the spaces may have a dramatic effect on costs and scheduling. The project team should carefully identify and assess needs for cleanliness levels, airflow requirements, and system types. For example, selecting and integrating a proper minienvironment in lieu of a larger cleanroom space may lead to better contamination control quality while reducing resources and costs.

4.8.1 Project size and scope summary

The project design team should prepare solutions to satisfy the statement of requirements. The process should incorporate project reviews at scheduled intervals with the owner groups. The effort should be conceptual in scope and include the following elements:

- a) Design documentation with support calculations
- b) Budget and schedule evaluation
- c) Outline of anticipated project complications
- d) Design alternatives, with discussions of pros and cons of each
- e) Recommendations for design alternatives
- f) Recommended project execution sequence (major elements)
- g) Statements on process systems
- h) Statement of the expected ease of facility maintenance
- i) Clear direction on the degree of flexibility expected in the design
- j) The concept solution agreed on by the user groups should be documented

4.8.2 Budget projections

Cost estimates should align with budget goals. Cleanroom construction projects are expensive and offer limited opportunities to reduce costs later in the project because the critical elements are installed during the final stages. Therefore, any changes during the construction process should be managed with a commitment to the original, agreed-on concept solution.

4.8.3 Schedule projections

Schedule projections for products that require long lead times or incorporate new technology should be realistic while permitting completion within an appropriate window of opportunity.

4.8.4 Development and constructability

Individuals experienced in cleanroom construction should help prepare cost and schedule estimates and should comment on the constructability of the proposed design.

5 DESIGN REQUIREMENTS

This section discusses factors to consider in developing cleanroom specifications. Descriptions of cleanroom features are included for reference and informational purposes only and should not be construed as specific design recommendations. The design team and end user should cooperate to develop specifications as described in section 4.

5.1 Airflow Pattern

Air patterns and the number of airflows supplied to a cleanroom are among the most important elements for effective contamination control in the cleanroom. Selection of an airflow pattern should be based on cleanliness requirements, characteristics of contaminants, and the layout of process equipment and the cleanroom facility.

5.1.1 Types of airflow patterns

Cleanroom airflow patterns may be unidirectional, nonunidirectional, or mixed. Airflow patterns for cleanrooms that are ISO Class 5 or cleaner are typically expected to be unidirectional. Nonunidirectional and mixed airflow patterns are commonly expected for ISO Class 6 or less-clean cleanrooms.

a) Airflow in unidirectional cleanrooms may be horizontal or vertical (Figure 3). In a horizontal design, air flows horizontally from a full wall of HEPA/ULPA filters through sidewall returns located in the opposite wall. Horizontal airflow is used where operations with stringent cleanliness requirements take place close to the wall of filters, and operations with sequentially decreasing cleanliness requirements take place farther from the wall of filters (downstream), as in aerospace cleanroom applications. In a vertical design, air typically flows downward from HEPA/ULPA filters located in the ceiling and through perforated flooring returns, or sometimes through sidewall returns (e.g., in a smaller room).

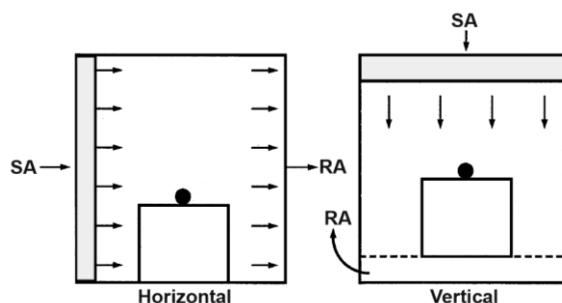


Figure 3. Unidirectional airflow (SA is supply air; RA is return air).

b) In nonunidirectional-airflow cleanrooms, air is supplied from HEPA/ULPA filters located in various terminal positions in the ceiling, and return air is through low sidewalls. Terminal filters (with or without air diffusers) may be distributed at equal intervals throughout the cleanroom, or filters without diffusers may be grouped over critical process areas. Because of the air distribution, airflow will be nonunidirectional (Figure 4). The use of filters without diffusers may provide a more directed flow and therefore lead to lower contaminant concentrations underneath. However, contaminant concentrations away from the area under the filter can become higher. Depending on the need, it may be preferable to use diffusers to provide well-mixed conditions throughout the cleanroom and use separate enclosures such as minienvironments to enhance contamination control where required.

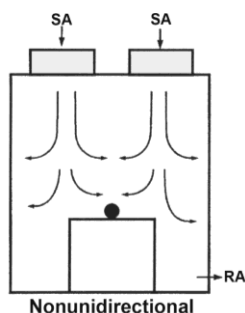


Figure 4. Nonunidirectional airflow (SA is supply air; RA is return air).

c) In mixed-airflow cleanrooms, unidirectional and nonunidirectional airflows are combined in the same room, depending on the process, activity, and contamination control needs (Figure 5).

Mixed-airflow cleanrooms are common across industries and applications. There are many types of system layouts (e.g., locations of supply air, and return or exhaust air) designed to accomplish contamination control needs. Various studies (experimental and modeling work) have suggested a variety of practical combinations to achieve effective transportation and removal of contaminants in cleanrooms of different cleanliness levels. For example, innovative fan dry coil unit (FDCU) return systems have been designed for industrial cleanrooms to improve the effectiveness and efficiency of environmental systems.

Separative enclosures such as unidirectional cabinets, isolators, or minienvironments may be used to enhance contamination control within a space housing specific process and activity.

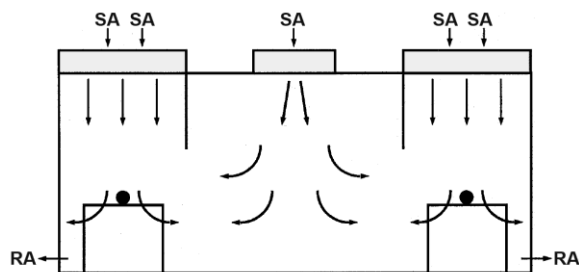


Figure 5. Mixed airflow (SA is supply air; RA is return air).

5.1.2 Measurement and Validation

For information and recommended practices for testing and characterizing airflows in a cleanroom, see IEST-RP-CC006.3.