Cleanrooms & HVAC Systems Design Fundamentals

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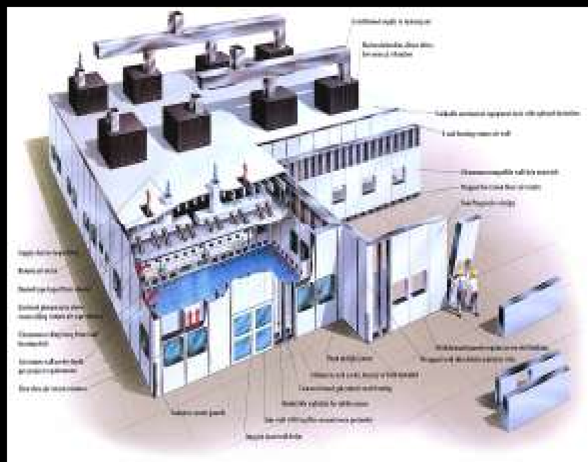
Contents

- Definition and classifications
- Standards
- Nonviable, viable particles (microbiological) and airborne molecular contamination (AMC)
- Particle sources
- Airflow quantity and pattern and floor arrangement
- Airlock and pressurization
- HVAC, plumbing, fire protection, and process systems
- Common devices and equipment
- Architectural construction materials, cleaning procedures, testing standards and construction cost
- CFD application

Introduction

Applications

- Semiconductor
- Microelectronic
- Pharmaceutical
- Biotechnology
- University
- Aerospace
- Automotive
- Hospital
- Miscellaneous



Cleanroom Definition

Definition - A specially constructed enclosed area, its environment has following controlled parameters:

- Temperature
- Humidity
- Sound and Vibration

Common Requirements

- Airflow Pattern
- Pressurization
- Particle Count
- Microbial Contamination
- Electrostatic Discharge (ESD)
- Gaseous Contamination
- Process Specific

Special & Unique Requirements

Standards

U.S. Federal Standard 209E	**Airborne particulate cleanliness classes in cleanrooms and clean zones (former US standard, canceled in November 2001)**

ISO Document	**ISO-14644: Cleanrooms and Associated Controlled Environments**
ISO-14644-1	Classification of Air Cleanliness
ISO-14644-2	Cleanroom Testing for Compliance
ISO-14644-3	Methods for Evaluating & Measuring Cleanrooms & Associated Controlled Environments
ISO-14644-4	Cleanroom Design & Construction
ISO-14644-5	Cleanroom Operations
ISO-14644-6	Terms, Definitions & Units
ISO-14644-7	Enhanced Clean Devices
ISO-14644-8	Molecular Contamination
ISO-14698-1	Biocontamination: Control General Principles
ISO-14698-2	Biocontamination: Evaluation & Interpretation of Data
ISO-14698-3	Biocontamination: Methodology for Measuring Efficiency of Cleaning Inert Surfaces

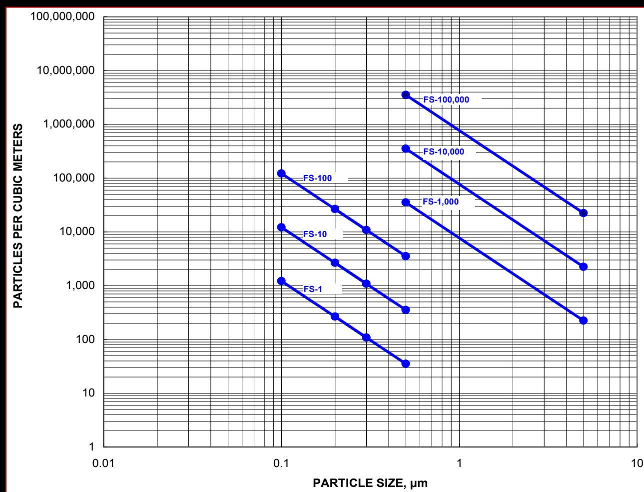
Classifications

Air Cleanliness Class Definition Comparison Between FS 209 and ISO 14644

FS 209 Class	ISO 14644 Class	0.1 µm		0.2 µm		0.3 µm		0.5 µm		1 µm		5.0 µm	
		FS 209 Particles/ft^3	ISO 14644 Particles/m^3	FS 209 Particles/ft^3	ISO 14644 Particles/m^3	FS 209 Particles/ft^3	ISO 14644 Particles/m^3	FS 209 Particles/ft^3	ISO 14644 Particles/m^3	FS 209 Particles/ft^3	ISO 14644 Particles/m^3	FS 209 Particles/ft^3	ISO 14644 Particles/m^3
	1		10		2								
	2		100		24		10		4				
1	3	35	1,000	7.5	237	3	102	1	35		8		
10	4	350	10,000	75	2,370	30	1,020	10	352		83		
100	5		100,000	750	23,700	300	10,200	100	3,520		832		29
1000	6		1,000,000		237,000		102,000	1,000	35,200		8,320	7	293
10,000	7							10,000	352,000		83,200	70	2,930
100,000	8							100,000	3,520,000		832,000	700	29,300
	9								35,200,000		8,320,000		293,000

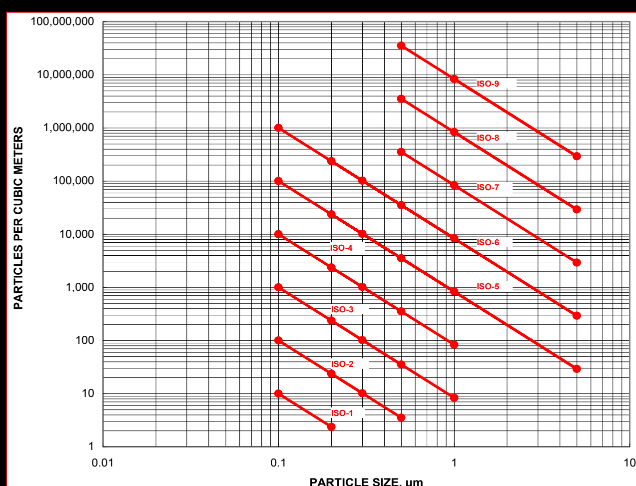
Classifications

Old Air Cleanliness Class Definition - FS 209



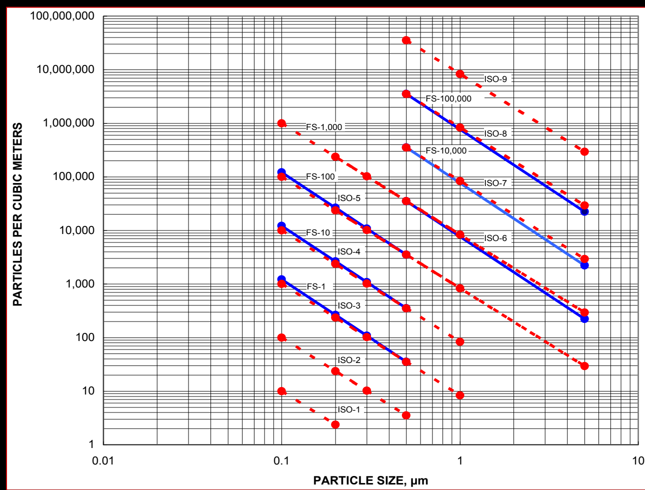
Classifications

Current Air Cleanliness Class Definition - ISO 14644



Classifications

Classification Comparison Between FS 209 and ISO 14644



Airborne Particles

Airborne particulates can be:

1. Particles larger than 100 microns can be seen with naked eyes.
2. Next step particles ranging from 0.001 to 100 microns are main interest of contamination for years.
3. Atoms and molecules used to be considered too small as industrial contamination, but not any more after introduction of molecular contamination.

Particle Sources & Control

Sources of Contamination		Description	Control Methods
External	Outdoor air	Infiltration through doors, and cracks at windows, and walls	Tighter exterior wall construction, exterior zone pressurization, vestibules at main entrances, and seal space penetrations.
		Makeup air entering through the air conditioning systems	Multiple level filtrations
	Indoor transfer air between rooms	Infiltration through doors, windows, and wall penetrations for pipes, ducts, etc.	Seal wall penetrations, multiple level pressurizations & depressurizations to obtain proper airflow directions
Internal	People	Largest source of internal particles: skin scales, hair, textile fibers	Garments, proper gowning procedures, air shower before entry
	Work surface shedding	Rubbing one item against another	Use cleanroom suitable or rated furniture
	Process equipment	Spray, painting, welding, grinding	Local filtration and exhaust
	Raw and semi-finished material	During transport	Equipment washing, cleaning and sterilization before entry, use airlock & pass-through
	Liquids, pressurized gases used in process	During preparation, processing and packaging	Local exhaust
	Chemicals used for cleaning	Out-gassing to room	Use cleanroom suitable or rated cleaners
	Room construction materials	Dust generated from wall, floor, ceiling, door, fibrous insulation	Constructed with special building materials

Microbiological Contamination & Control

- Unlike non-viable particles, which can't reproduce, microorganisms could reproduce at a rapid speed if nutrition and environment are favorable.
- Microorganism can be classified as bacteria, algae, fungi, protozoa and viruses. Some of these are essential, useful and harmless, while others are harmful and dangerous.

Control Methods

Physical:

- Heat
- Radiation
- Filtration

Chemical:

- Sterilization
- Disinfection

Airborne Particle Physical Controls

Filtration

Utilizing HEPA & ULPA filters to remove particles from supply air

- HEPA: 99.97% (Ef.@0.3µm)
- ULPA: 99.9997% (Ef.@0.12µm)

Dilution

Diluting internally contaminated air with clean, filtered air

- Higher air change rate, better dilution.

Isolation

Containing or isolating particle generations with barriers

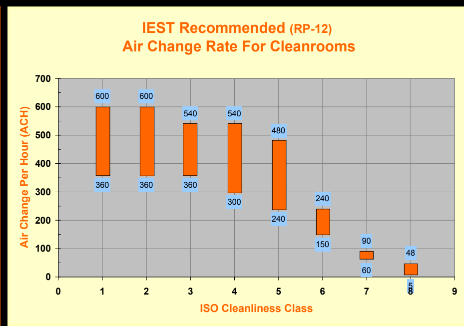
- Process exhaust
- Mini-environment

Typical Ceiling Filter Coverage

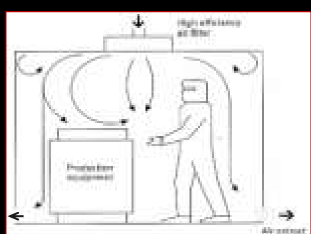
Class		Ceiling Filter Coverage	HEPA or ULPA
US 209	**ISO**		
	9	5% - 15%	HEPA
100,000	8	5% - 15%	
10,000	7	15% - 20%	
1,000	6	25% - 40%	
100	5	35% - 70%	
10	4	60% - 90%	ULPA
1	3	60% - 100%	
	2	80% - 100%	
	1	80% - 100%	

Room Airflow Quantity
(Traditional Methodology)

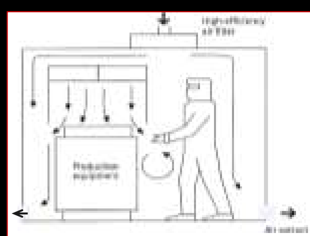
Classification		Air Change Per Hour Range
ISO Class	FS-209 Class	
8	100,000	5 – 48
7	10,000	60 – 90
6	1,000	150 – 240
5	100	240 – 480
4	10	300 – 540
3	1	360 – 540
2		360 – 600
1		



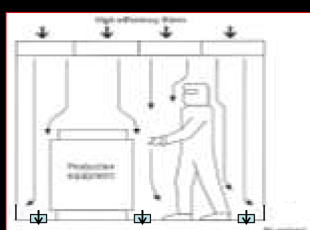
Airflow Patterns



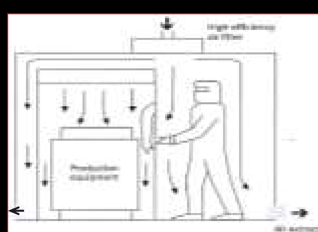
Non-Unidirectional (Conventional) Flow



Mixed Flow



Unidirectional Flow



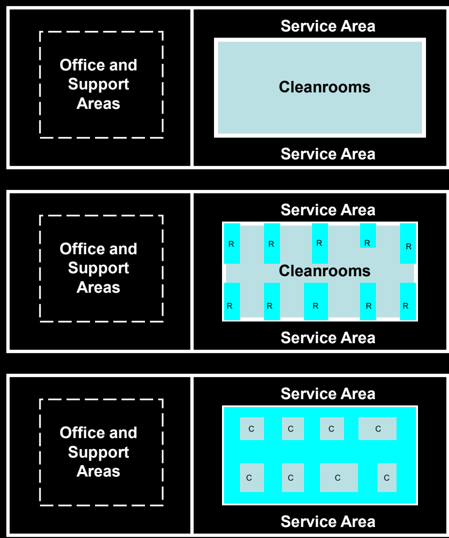
Mini-Environment Flow

Cleanroom Floor Arrangements

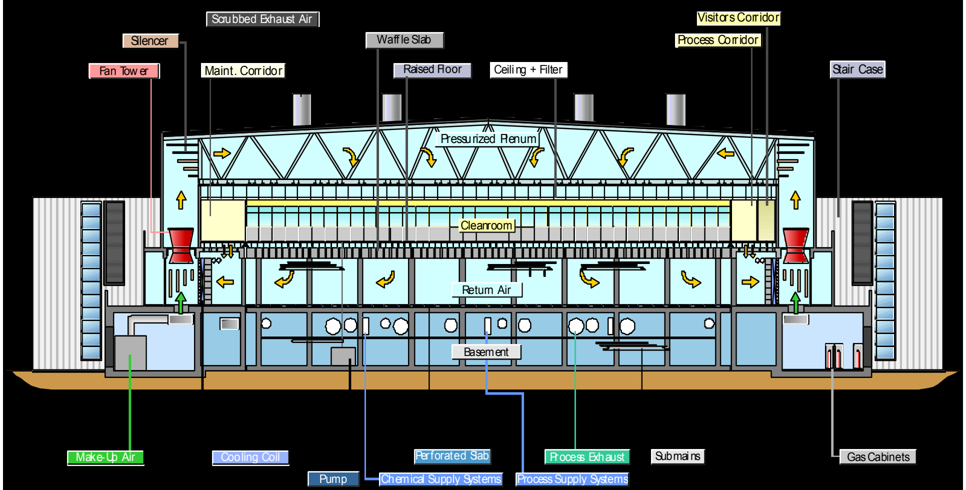
Ballroom

Service Chase

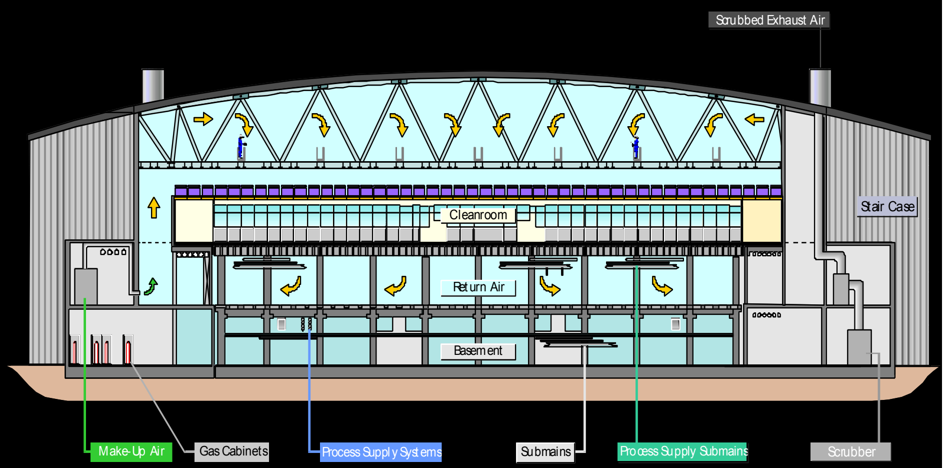
Mini-Environment



Example – Fan Tower Arrangement



Example – Fan Filter Units Arrangement



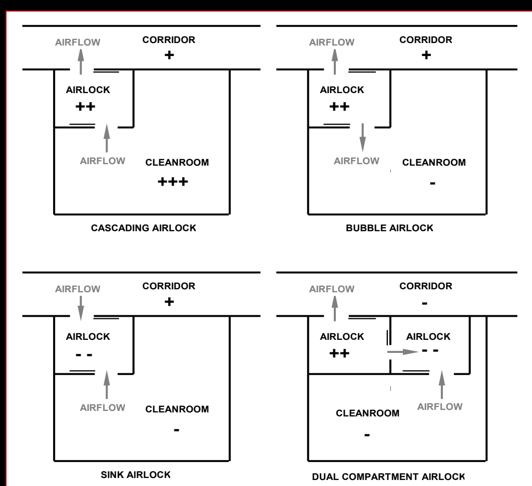
Control Airflows Between Rooms
Air Lock

Air Lock

An intermediate room between adjacent areas with different cleanliness to prevent airborne cross contamination

Type

- Cascading
- Bubble
- Sink
- Dual Compartment



Control Airflows Between Rooms Air Lock

Application

- Positive or Negative Pressure?
- Has Fume or Bio Contamination?
- Containment Needed?
- Personal Protection Needed?

Type of Cleanroom	Selection of Airlock	Functionality of Airlock	Relative Pressure Relationship
• Positive pressure • No fume or bio agent • No containment needed	Cascading	• Prevent cleanroom being contaminated from dirty corridor air • Prevent cleanroom being contaminated from surrounding spaces through cracks	Cleanroom: +++ Airlock: ++ Corridor: +
• Negative pressure • Has fume or bio agent contamination • Containment needed	Bubble	• Prevent cleanroom being contaminated from dirty corridor air • Prevent cleanroom fume or bio agent releas ing to corridor	Cleanroom: - Airlock: ++ Corridor: +
• Negative pressure • Has fume or bio agent contamination • Containment needed	Sink	• Prevent cleanroom being contaminated from dirty corridor air • Allow cleanroom fume or bio agent releas ing to airlock. No personal protective equipment is needed	Cleanroom: - Airlock: - - Corridor: +
• Negative pressure • Has toxic fume or hazardous bio agent contamination, or has potent compound substan ces • Containment needed • Personal protecti on needed	Dual Compart - ment	• Prevent cleanroom being contaminated from dirty corridor air • Prevent cleanroom fume or bio agent releas ing to corridor • Personal protective equipment (such as pressurized suit and respirat or) is required	Cleanroom: - Neg. Airlock: - - Pos. Airlock: ++ Corridor: -

Control Airflows Between Rooms Pressurization

- Air should always flows from high pressure to low pressure area. Normally the desired flow path should be from the area of cleanest, to less-clean, to less-contaminated, and then to dirty areas.
- **Pressurization** is defined as a technique that air pressure differences are created mechanically between rooms to introduce intentional air movement paths through room leakage openings. These openings could be either designated, such as doorways, or undesignated, such as air gaps around doorframes or other cracks.

Control Airflows Between Rooms
Pressurization

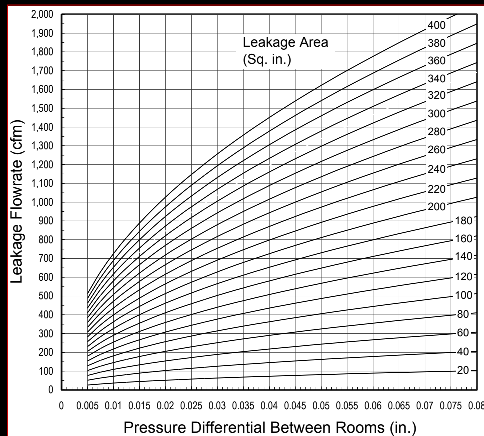
Single Room Pressurization

- Room **pressurization**

  Entering (SA) airflow rate is **higher** than leaving (EA + RA) airflow rate in the room, room net (offset) flow is positive.

- Room **depressurization**

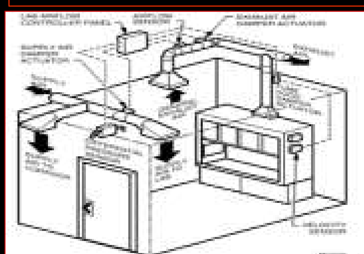
  Entering (SA) airflow rate is **lower** than leaving (EA + RA) airflow rate in the room, room net (offset) flow is negative.

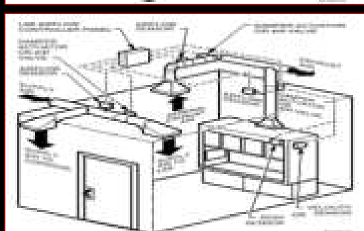


Room Net Flow Rate vs. Pressure Differential

Control Airflows Between Rooms
Pressurization

Single Room Pressurization





Room Pressure Control Strategies

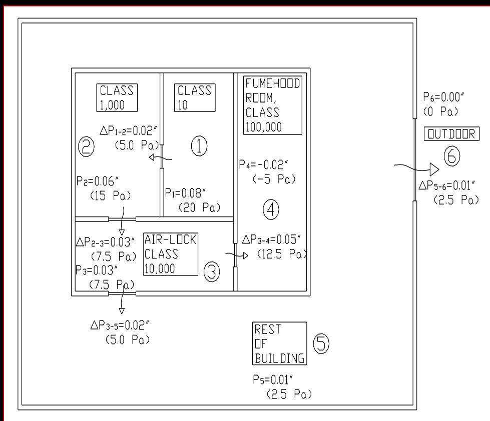
Room Airtightness is the key element in the relationship between the room's flow **offset value** and the **resulting pressure differential**, and each room airtightness is unique and unknown unless tested.

The treatment of the room net flow "offset" value defines a pressurization control strategy. Typical pressurization control techniques:

- **Direct Pressure-Differential Control**
- **Differential Flow Tracking Control**
- **Hybrid Control**

Control Airflows Between Rooms Pressurization

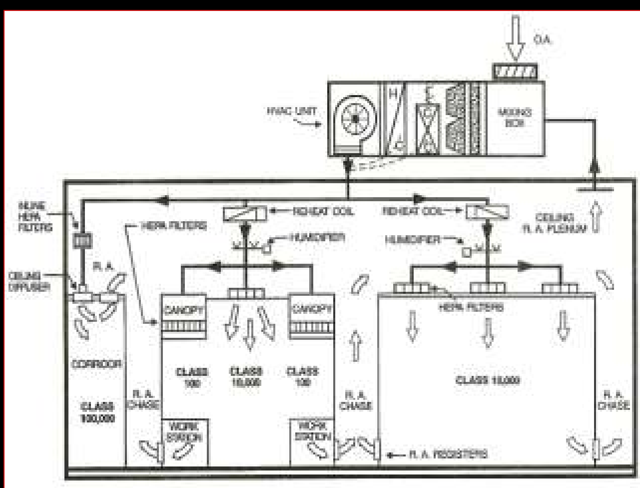
Multiple Room (Suite) Pressurization



Room Pressure & Flow (P&F) diagram (suite, zone or floor) – The basis of continuous validation and qualification of room pressure control:

- Indicate airflow design settings (values) of all supply, return and exhaust registers.
- Indicate the desired room pressure value with an acceptable tolerance.
- Indicate the resulting leakage flow directions (due to room pressure differentials) and their estimated leakage values through doors at closed-door condition.

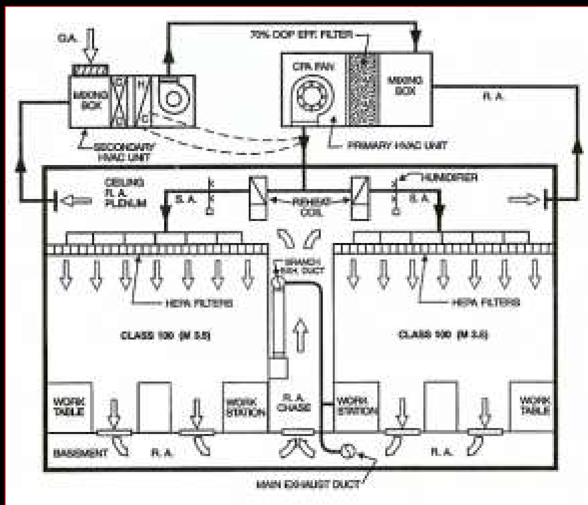
Typical HVAC Systems



FS209 Class 10,000, 100,000

ISO Class 7, 8

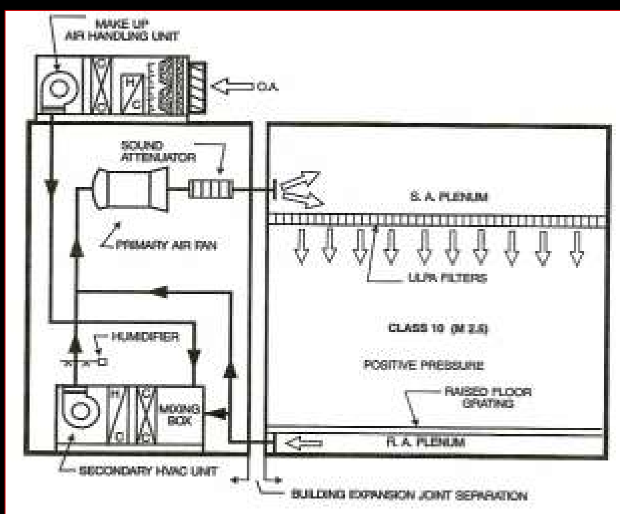
Typical HVAC Systems



FS209 Class
100, 1,000

ISO Class
5, 6

Typical HVAC Systems

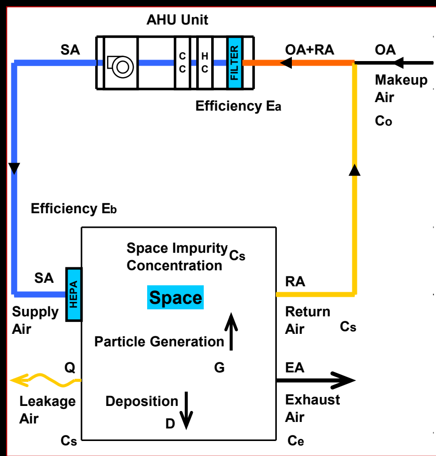


FS209 Class
1, 10

ISO Class
3, 4

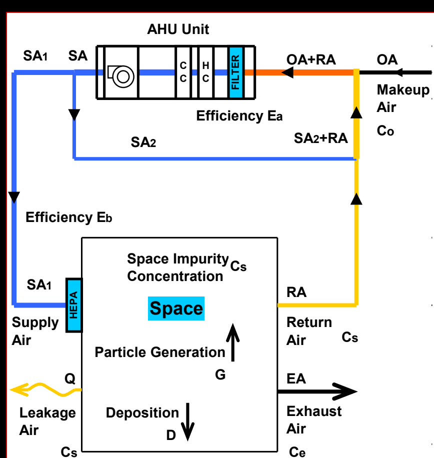
Basic HVAC Flow Diagrams

Configuration-1: Conventional Primary loop



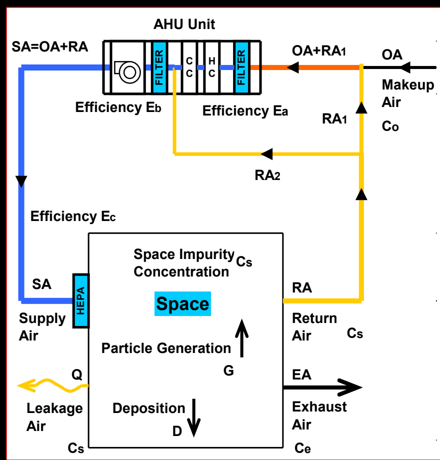
Basic HVAC Flow Diagrams

Configuration-2: Primary loop with supply bypass



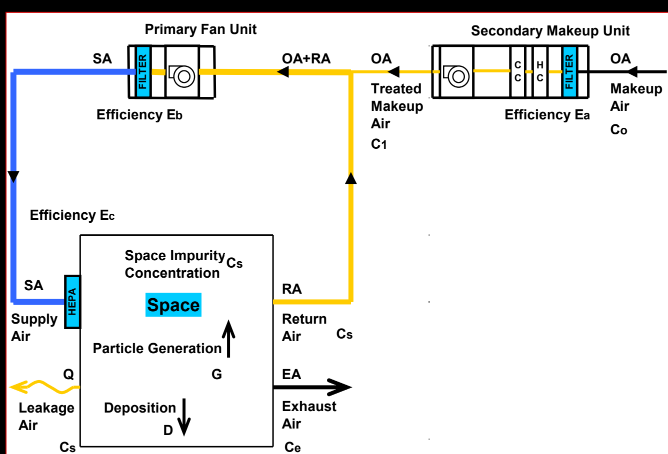
Basic HVAC Flow Diagrams

Configuration-3: Primary loop with dual returns



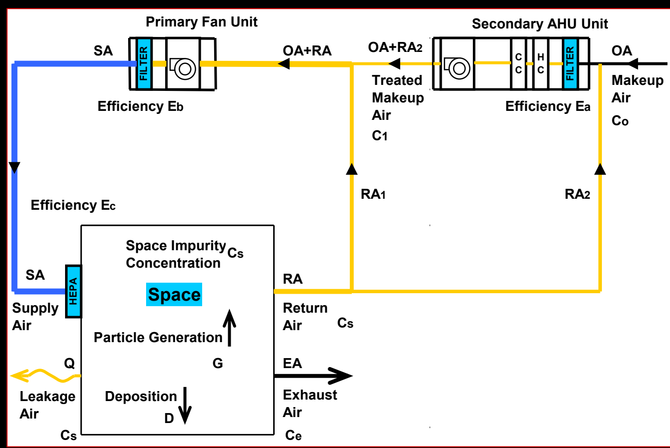
Basic HVAC Flow Diagrams

Configuration-4: Primary loop plus secondary makeup unit



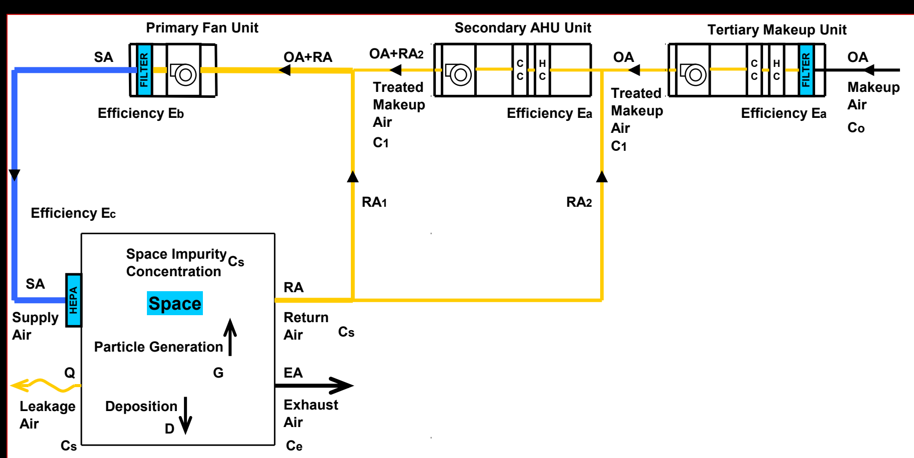
Basic HVAC Flow Diagrams

Configuration-5: Primary loop plus secondary AHU unit with dual returns

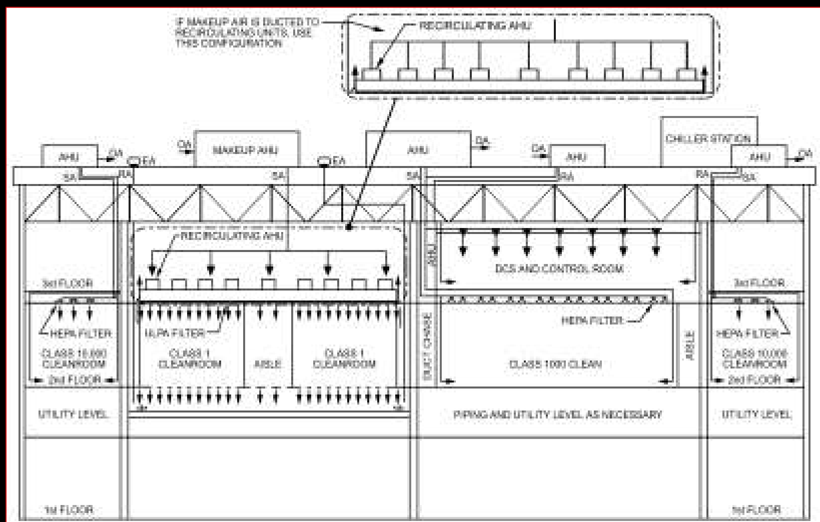


Basic HVAC Flow Diagrams

Configuration-6: Primary loop plus secondary AHU unit and tertiary makeup unit with dual returns



Building Section Schematic



Semiconductor Fabrication Facility

Process and Building Systems

Building Systems

- City water & gas services
- Cold/hot water distributions
- Gas distributions
- Storm, sanitary & vent
- Fire pump & automatic sprinkler systems
- Emergency power generator
- HVAC & Indoor comfort
- Building management

Cleanroom HVAC&R

- Make-up system
- Recirculation system
- Return air system
- Temperature & humidity controls
- Room pressure control
- Noise and vibration control
- Hydronic heating
- Comfort chilled water
- Cooling tower water
- Particle counting

Cleanroom Process

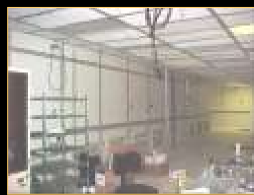
- Gas detection
- Static control
- RO and DI waters
- Process chilled water
- Chemical gases and storages
- Solvent drain and collection
- Solvent gas exhaust
- Process vacuum
- Scrubbed exhaust
- House vacuum
- Acid drain and waste neutralization
- Clean dry air
- Instrumentation air & control

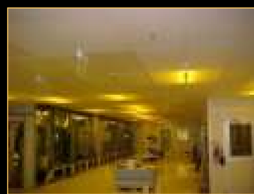

Typical Specified Cleanroom Components, Devices & Equipment
HEPA / ULPA Filter
Air Filtration
Fan-Filter Ceiling Module
Bag-in/Bag-out multiple filters
- Against biological, chemical & radiological materials
Air Sampling
Handhold Particle Counter
Air Particle Sensor
Portable Particle Counter
Pharmaceutical cGMP Particle Monitoring & Validation
Microbial Air Sampler & Agar Media

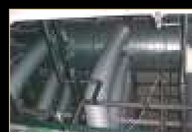

Typical Specified Cleanroom Components, Devices & Equipment
Air Valve
Precision Room Pressure Transducer
Floor Grate & Perforated Panel
Isolator (Glove Box)
Soft Wall
Small Mini-Environment
Product Pass-through

Cleanroom Building Exterior and Interior

Building Finished Exterior

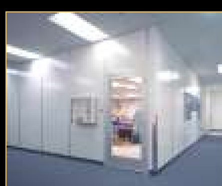






Cleanrooms in Construction

Finished Cleanrooms



Small Class 100,000 Cleanroom

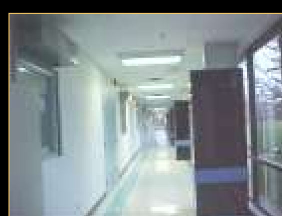
Interior Hallway

Window on Exterior Wall

Window on Interior Wall

Class 10, Raised Floor

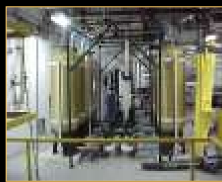
Gowning Area, Raised Floor



Service Hallway Enclosing Cleanrooms

Cleanroom Utility and Support

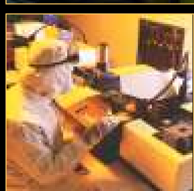
Large DI Water System

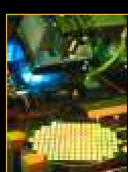


AHU Unit for Office/ Administration Areas

Steam-Hot Water Exchange Unit (Packaged)

Cleanrooms In Operation





Cleanroom Construction Materials

Classification	FS Class 1	FS Class 10	FS Class 100	FS Class 1,000	FS Class 10,000	FS Class 100,000
	ISO Class 1, 2 & 3	ISO Class 4	ISO Class 5	ISO Class 6	ISO Class 7	ISO Class 8 & 9
Wall System	Aluminum Component			Aluminum Component or Metal Stud		
Wall Panel	Honeycomb Aluminum Conductive Finish			Aluminum Polystyrene Core or Epoxy Coated Steel Laminated over Drywall		Vinyl or Epoxy Coated Drywall
Paint	Epoxy			Epoxy / Latex		Latex
Ceiling Grid	2" Aluminum Gel Seal Ceiling System			1½" Steel Gasketed		
Grid Support	All thread with Strut & Turn buckles			12 ga wire to grid, 10 ga wire to filter @ Corner of Grid Intersection Only		
Floor	Raised Floor with Perforated / Grated Access				Concrete Covered with Epoxy Solids or Sheet Vinyl	
Air Return	Floor				Low Sidewall	Low Sidewall or Ceiling

ISO Construction Cleaning Procedures

Stage	Purpose	Responsible party	Method	Standard
Stage 1 — Clean during demolition or preliminary construction such as framing for wall installation.	Preventing unnecessary dust concentration in places that will be difficult to reach during later construction.	Contractor. If the construction contractor has no relevant experience in cleanroom cleaning, it is advisable to hire a professional cleaning contractor specializing in cleanroom cleaning.	Vacuum clean upon completion.	Visual-clean.
Stage 2 — Clean during utility installation.	Removing local contaminants caused by installing electricity, gas, water, etc.	Installation engineer.	Vacuum clean; wipe-down piping and fixtures with moistened wipers upon completion. The use of vacuum cleaning and/or other cleaning materials is necessary.	Visual-clean.
Stage 3 — Clean during early construction.	Cleaning all visible contamination from ceilings, walls, floors, (filter mountings), etc. after completion of construction and installation activities.	Cleaning contractor.	Vacuum clean; wipe-down piping and fixtures with moistened wipers. Application of protective floor sealants is generally a particle generating activity. If this is necessary, it should be applied at this time.	Visual-clean.
Stage 4 — Prepare for air conditioning ductwork installation.	Cleaning any dust from ductwork sections before installing using a vacuum cleaner and wipers. Meanwhile, a positive pressure should be introduced to the cleanroom.	Installation engineer and cleaning contractor.	Vacuum clean; wipe down with moistened wipers.	Wiper-clean.

ISO Construction Cleaning Procedures

Stage	Purpose	Responsible party	Method	Standard
Stage 5 — Clean before mounting all air filters into the system.	Removing deposited or settled dust, or both, from ceilings, walls, and floors.	Cleaning contractor.	Wipe down with moistened wipers.	Wiper-clean.
Stage 6 — Mount the (HEPA/ULPA) filters into the air systems	Removing possible contamination caused by the mounting operation.	Cleanroom HVAC filter engineer/ technician.	Clean all surface edges on all sides.	Wiper-clean.
Stage 7 — Adjust the air conditioning equipment.	Removing suspended dust from the airflow and creating overpressure installation, including the filters.	Cleanroom HVAC filter engineer/ technician.	Air conditioning air flushing operation.	Wiper-clean.
Stage 8 — Upgrade the room into prescribed classification.	Removing all deposited and clinging dust from every surface (in order: ceilings, walls, equipment, floors).	A professional cleanroom cleaning by personnel specially instructed on regulations, routing and behaviour.	Wipe down with moistened wipers.	Wiper-clean.
Stage 9 — Approve installation.	Verifying the cleanroom to the prescribed design specifications. Customer acceptance.	Installation engineer and certification engineer.	Monitor airborne and surface particles, air velocities, temperature and humidity.	Wiper-clean. Results should conform to agreed design criteria.
Stage 10 — Clean daily and periodically	Maintaining the cleanroom in long-term compliance with designed classification. Microbiological cleaning and testing begins in biocleanrooms.	Cleanroom manager/cleaning contractor.	Listed in F.1 to F.8.	A tailor-made cleaning programme for the cleanroom, accounting for the specific demands of the production process and the customer. Routine testing of critical operation parameters.

NOTE 1 During Stages 4 to 10, all high-efficiency and ultra-high-purity components, such as filters, ducts, etc., should arrive on site protected by plastic or foil covers on both ends. Covers should only be removed when ready for use. NOTE 2 During Stages 6 to 10, all activities should be done wearing prescribed cleanroom clothing.

Cleanroom Testing

Required Testing (ISO 14644-2)

Schedule of Tests to Demonstrate Continuing Compliance

Test Parameter	*Class*	*Maximum Time Interval*	*Test Procedure*
Particle Count Test	<= ISO 5	6 Months	ISO 14644-1 Annex A
	> ISO 5	12 Months	
Air Pressure Difference	All Classes	12 Months	ISO 14644-1 Annex B5
Airflow	All Classes	12 Months	ISO 14644-1 Annex B4

Optional Testing (ISO 14644-2)

Schedule of Additional Optional Tests

Test Parameter	*Class*	*Maximum Time Interval*	*Test Procedure*
Installed Filter Leakage	All Classes	24 Months	ISO 14644-3 Annex B6
Containment Leakage	All Classes	24 Months	ISO 14644-3 Annex B4
Recovery	All Classes	24 Months	ISO 14644-3 Annex B13
Airflow Visualization	All Classes	24 Months	ISO 14644-3 Annex B7

Cleanroom Design Problems & Validation

Common Design Problems

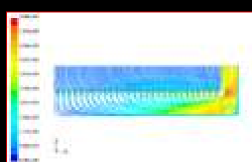
- Poor laminarity
- Fail to pressurize to specified pressure levels
- Local stagnation near point of service
- Ineffective chemical vapor exhaust
- Too high noise
- Temperature & humidity variations above specifications

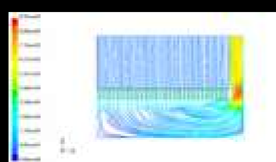
How to Ensure Quality During Design Phase?

- Engineer's design knowledge & experience
- Mock-up or scale-down model
- CFD validation

CFD Applications

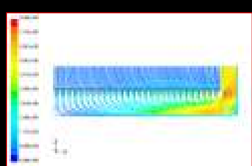
Cleanroom with 35% FA Floor Panels

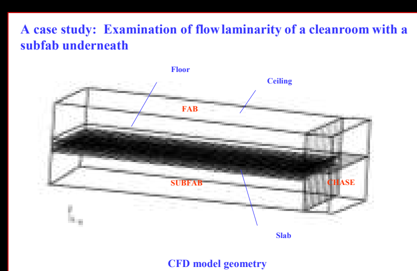




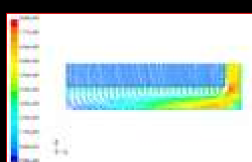
Narrower Cleanroom with 35% FA Floor Panels

Cleanroom with 20% FA Floor Panels

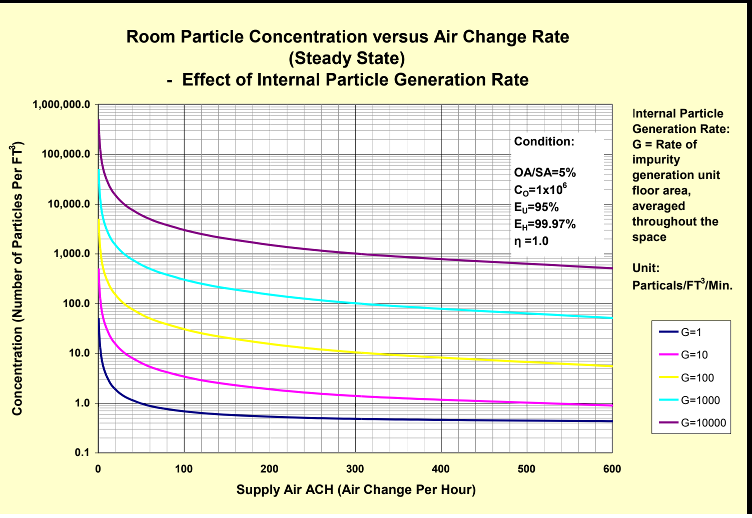




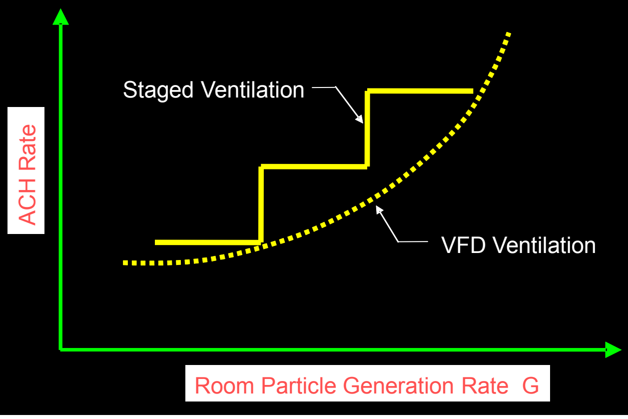
Cleanroom with 10% FA Floor Panels



Technology Trend – Determination of Airflow Rate Based on Particle Generation Rate During Design Phase



Technology Trend – Provide Airflow Rate Based on Particle Generation Rate During Operating Phase



The goal is to stage the ventilation rate to maintain the same room cleanliness level through particle sensing during all modes (occupied and unoccupied)