CASE STUDY – CLEAN ROOM DESIGN

Microelectronics Manufacturing Facility
Agenda

- Terminology
- Clean Room Design Basics
  - ISO Classifications
  - Filtration and air-change rates
  - Filter basics
- Case Study
  - Facility description
  - Project design criteria
  - HVAC system descriptions
  - Energy efficiency considerations
- Conclusion / Q & A
Relevant Terminology

1. **ACH/ACR**: Air changes per hour / air change rate
2. **Air Lock**: A transitional room between two other rooms of different cleanliness.
3. **Challenge**: An airborne dispersion of particles used to test filter integrity and efficiency.
4. **Cleanroom**: A room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the room and in which other relevant parameters, e.g. temperature, humidity and pressure are controlled as necessary (ISO 14644-1 definition).
5. **DOP**: *Dioctyl phthalate*, and aerosol used for filter challenge.
7. **HEPA**: High-efficiency particular air filter.
8. **ISO 14644-1**: International Organization for Standardization standard that defines airborne particulate cleanliness classifications
9. **Unidirectional (Laminar) flow**: Air flowing at a constant and uniform velocity and direction.
10. **ULPA**: Ultra-low penetration air filter
11. **Particle concentration**: The number of particles per unit of air.
Airborne Particulates

Perspective: 98% of all particles found in indoor air are smaller than 1 micron in size.
### Filter MERV Ratings

#### MERV RATING CHART

<table>
<thead>
<tr>
<th>Standard 52.5 Minimum Efficiency Reporting Value</th>
<th>Dust Spot Efficiency</th>
<th>Arrestance</th>
<th>Typical Controlled Contaminant</th>
<th>Typical Applications and Limitations</th>
<th>Typical Air Filter/Cleaner Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>n/a</td>
<td>&gt;95%</td>
<td>0.3-0.5 pm Particle Size</td>
<td>Commercial Buildings</td>
<td>Pleated Filters: Disposable, extended surface area, thick with cotton-polyester material, cardboard frame.</td>
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<td>Commercial Buildings</td>
<td>Pleated Filters: Disposable, extended surface area, thick with cotton-polyester material, cardboard frame.</td>
</tr>
</tbody>
</table>

**MERV 13 is standard for a Class A office design.**

**ULPA Filters = MERV 19-20**

**HEPA filters = MERV 17-18**
Filter Media

Older generations of HEPA filters used aluminum pleat separators.

Glass fiber paper technology.

Today’s micro-pleat media technology allows for lower pressure drop and reduced filter media depth.
### Airborne Particulate Cleanliness Classifications

<table>
<thead>
<tr>
<th>ISO 14644-1</th>
<th>FEDERAL STANDARD 209E</th>
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<tbody>
<tr>
<td><strong>ISO Class</strong></td>
<td><strong>English</strong></td>
</tr>
<tr>
<td>ISO 1</td>
<td></td>
</tr>
<tr>
<td>ISO 2</td>
<td></td>
</tr>
<tr>
<td>ISO 3</td>
<td>1</td>
</tr>
<tr>
<td>ISO 4</td>
<td>10</td>
</tr>
<tr>
<td>ISO 5</td>
<td>100</td>
</tr>
<tr>
<td>ISO 6</td>
<td>1,000</td>
</tr>
<tr>
<td>ISO 7</td>
<td>10,000</td>
</tr>
<tr>
<td>ISO 8</td>
<td>100,000</td>
</tr>
<tr>
<td>ISO 9</td>
<td>N/A</td>
</tr>
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</table>

Standard 209E classifications are out-of-date. This standard was officially retired in 2001.
# Airborne Particulate Cleanliness

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Number of Particles per Cubic Meter by Micrometer Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1 micron</td>
</tr>
<tr>
<td>ISO1</td>
<td>10</td>
</tr>
<tr>
<td>ISO2</td>
<td>100</td>
</tr>
<tr>
<td>ISO3</td>
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<td>ISO4</td>
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<td>ISO6</td>
<td>1,000,000</td>
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<tr>
<td>ISO7</td>
<td></td>
</tr>
<tr>
<td>ISO8</td>
<td></td>
</tr>
<tr>
<td>ISO9</td>
<td></td>
</tr>
</tbody>
</table>

*Perspective: A strand of human hair is about 40-100 microns in diameter.*
## Air Change Rates / Ceiling HEPA Coverage

<table>
<thead>
<tr>
<th>Class ISO 146144-1 (Federal Standard 209E)</th>
<th>Average Airflow Velocity m/s (ft/min)</th>
<th>Air Changes Per Hour</th>
<th>Ceiling Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 8 (Class 100,000)</td>
<td>0.005 - 0.041 (1 - 8)</td>
<td>5 - 48</td>
<td>5 - 15%</td>
</tr>
<tr>
<td>ISO 7 (Class 10,000)</td>
<td>0.051 - 0.076 (10 - 15)</td>
<td>60 - 90</td>
<td>15 - 20%</td>
</tr>
<tr>
<td>ISO 6 (Class 1,000)</td>
<td>0.127 - 0.203 (25 - 40)</td>
<td>150 - 240</td>
<td>25 - 40%</td>
</tr>
<tr>
<td>ISO 5 (Class 100)</td>
<td>0.203 - 0.406 (40 - 80)</td>
<td>240 - 480</td>
<td>35 - 70%</td>
</tr>
<tr>
<td>ISO 4 (Class 10)</td>
<td>0.254 - 0.451 (50 - 90)</td>
<td>300 - 540</td>
<td>50 - 90%</td>
</tr>
<tr>
<td>ISO 3 (Class 1)</td>
<td>0.305 - 0.457 (60 - 90)</td>
<td>360 - 540</td>
<td>60 - 100%</td>
</tr>
<tr>
<td>ISO 1-2</td>
<td>0.305 - 0.508 (60 - 100)</td>
<td>360 - 600</td>
<td>80 - 100%</td>
</tr>
</tbody>
</table>

- Uni-directional air flow in cleanroom applies to ISO 6 and above
- 300 ACH = 45 CFM/SF in a cleanroom with a 9’ ceiling
- % of cleanroom ceiling area occupied by filter modules
Case Study Introductory Notes

Project specifics – location, company, etc. are confidential.

Photos used in this presentation are generic, unless otherwise noted.

The Case Study project was delivered to the Owner as a design-assist, with contractor involvement early in the design process.
Design Criteria – Clean Room

ISO Class 6 Environment:
- 36,000 SF open-bay type cleanroom
- Positive room pressure controlled to +0.05” WC
- Room conditions at 69°F and 40% RH
- Minimum of 120 air-changes per hour
- 33% ceiling HEPA coverage
- Unidirectional vertical airflow
- 12’ ceiling height

Room features:
- Smooth, cleanable interior surfaces
- Gasketed grid ceiling with luminaires, HEPA modules, and systems components (sprinkler heads, smoke detectors, etc.), smoke exhaust grilles
- Perforated floor serves as return air path
- Wafer manufacturing tools with specialized solvent and acid exhaust systems
HVAC Design – Clean Room

**Make-up Air AHUs:**
- 100% outside air delivery to plenum
- Temperature and humidity control of make-up air
- (6) units, each sized for 30,000 CFM
- Make-up air flow is 5 CFM/SF, or 25 ACH.

**Recirculating AHUs:**
- (40) units, each sized for 24,000 CFM
- Recirculated air flow is 26.7 CFM/SF, or 133 ACH.
- Powder-coated finish

**Exhaust Systems:**
- Acid Exhaust (2.8 CFM/SF), with scrubbers and N+1 redundancy
- Solvent Exhaust (0.8 CFM/SF), N+1 redundancy.
- Smoke Exhaust (2.7 CFM/SF)
Building Cross-section

Make-up AHU’s
Recirculating AHU’s
Ducted HEPA terminals

ISO Class 6 Cleanroom
Perforated floor slab for RA path

This multi-level configuration is often applied to more stringent ISO cleanroom classifications.
HEPA filter module arrangement in a 2’ X 4’ clean-room sealed ceiling grid

Overall Ceiling HEPA coverage is 33%

Manufacturing Level Ceiling Plan
Filter Terminals

SA connection – AHU supply fan provides required static

Balancing damper, accessible from the manufacturing level

Filter media

Knife-edge seal with gel gasket
Supply air plenums are connected to provide a level of redundancy between recirculation units.

Supply air plenums with multiple take-off fittings to HEPA ceiling modules.
Fan Attic Level Plan

Make-up air units, with outside air hoods above

The entire fan attic level serves as a mixed air plenum.

Exhaust mains

Recirculated air units, with downward discharge to supply plenums at the Interstitial level.
Fan Attic Level

AHU support structure

Supply air plenum (flex ducts to HEPAs not shown).

Smoke exhaust

Recirculated air units, supported from structural framework.
Clean Room Make-up Air Units

Outside air from roof hood

Pre- and intermediate filtration

8-row, 10 FPI dehumidification coil sized for 400 FPM face velocity and 1.13” DP

Outside air make-up AHU design with complete temperature and humidity control.

Units are scheduled for 8.0” TSP, and only 0.75” ESP.

8-row, 8 FPI cooling coil sized for 400 FPM face velocity and 0.83” DP

Direct-drive fan array (4 fans) (535 CFM/BHP), N+1

Air is HEPA filtered to maximize the service life of terminal HEPAs
Fan Array Technology

Many advantages over single-fan systems:

✓ Equipment redundancy
✓ Less vibration
✓ Lower noise
✓ Less space required
✓ Tighter duty selection
✓ Direct drive fans – no belt loss
Psychrometrics – Make-up Air Units

Make-up Air AHU cooling coil:
EA = 85°F db/70°F wb
LA = 52°F db/52°F wb

Make-up Air AHU dehumidification coil:
EA = 53°F db/53°F wb
LA = 42°F db/42°F wb

Outside air conditions at Maximum wb temp and coincident db temp

Room conditions:
69°F db/40% RH
Clean Room Recirculation Units

- Simple, low-pressure recirculating AHU design with very low unit pressure drop
- Units are scheduled for 3.0” TSP, which includes terminal HEPA DP.
- 3-row, 8 FPI cooling coil sized for 400 FPM maximum face velocity and 0.17” DP
- Direct-drive fan with custom wheel width (1500 CFM/BHP)
Psychrometrics – Recirculation Units

**Recirculating AHU cooling coil:**
EA = 72°F db/59°F wb
LA = 64°F db/57°F wb

**Room conditions:**
69°F db/40% RH

**Note:**
The recirculating AHU Cooling process is 100% sensible cooling. Condensate does not collect on the cooling coil.
Energy Efficiency Considerations

Cleanrooms can easily be 50X more energy-intensive than typical office space, and that is heavily impacted by the fan energy required to deliver the prescribed air-change rate at the required filtration level. The room cooling load is often a small fraction of the energy demand. Things to prioritize:

1. Efficient fan selection – direct-drive, with custom wheel selection
2. High-efficiency fan motors
3. Low system pressure drop – size ductwork for low velocity and minimize length of duct runs
4. Low component pressure drop – keep air velocity (and pressure drop) across coils and filters as low as practical
Other Energy Efficiency Considerations

Other design considerations:
1. AHU cooling coils are sized for a low face velocity (400 FPM) and air temperature drop (less than 8°F), which allows coil selections to have 3 rows/8 FPI, and minimized pressure drop (0.17” WC) as a result.
2. Because cooling coil temperature drop is minimized, chilled water supply temperature can be increased (57°F) during mild and cold weather, which further increases the efficiency of the chilled water plant.
3. Pre-filters: Intended to maximize the life-span of the HEPA terminal filters. 400 FPM face velocity.
4. Supply fan speeds are modulated through VFDs as a function of filter loading.
5. Limiting the cleanroom ceiling height to 12’ helps minimize the CFM required to maintain ACH rates.
Specialty Exhaust Systems

Acid and solvent exhaust systems: Epoxy-lined stainless-steel exhaust ductwork with welded seams and flanged connections. Acid exhaust stream is routed through a scrubber system prior to being discharged at high velocity vertical plume discharge at roof level.

Actual project photo – Sub-Fab Level
Recommended References:

- ASHRAE Applications Volume, Chapter 18: Clean Spaces
- ISO Cleanroom Standards
- Manufacturer web-sites:
  - Cam-fil (filters)
  - Flanders (filters)
  - Price Design Guide (air devices)
Questions?
Thank you!

GIVEN THE PACE OF TECHNOLOGY, I PROPOSE WE LEAVE MATH TO THE MACHINES AND GO PLAY OUTSIDE.
Contact Information

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