Presentation Coverage

- **Sustainable development in cleanroom buildings**
  - Energy perspective

- **Techniques and strategies in cleanroom design and operation**
  - Programming, design and construction
  - Cleanroom Systems
    - Optimizing HVAC systems (air and water systems)
    - Improving power systems and process in cleanrooms

- **Examples**

- **Best Practice**
Cleanroom Energy Use

- Chillers and Pumps: 21%
- Recirc and Make-up Fans: 19%
- Process Tools: 34%
- Exhaust Fans: 7%
- Nitrogen Plant: 7%
- Process Water Pumping: 4%
- Support: 3%
- DI Water: 5%

Source: Xu et al. 2002. Lawrence Berkeley National Laboratory Report LBNL-49220, Berkeley, California

Energy Systems

- HVAC Pumps: 20%
- Fans: 30%
- Tools: 12%
- Air Compressors: 2%
- Nitrogen Plant: 12%
- Lighting: 4%
- Plugs: 4%
- Misc: 4%
- Chillers: 14%
Cleanroom Benchmarking

Facility 1
- Hot Water & Steam: 23%
- Chilled Water: 19%
- Cleanroom Fans: 16%
- Other Misc.: 8%
- Process: 13%
- Cleanroom Lights: 1%
- Compressed Air & Process Vacuum: 8%

Facility 2
- Hot Water, Steam, and Cafeteria: 17%
- Total Chilled Water: 20%
- Cleanroom Fans: 27%
- Other Misc.: 10%
- Process: 8%
- Cleanroom Lights: 1%
- Compressed Air: 7%
- Office (Lights, Plugs): 9%

Facility 3
- Hot Water & Steam: 7%
- Office (Lights, Plugs): 6%
- Process: 35%
- Total Chilled Water: 18%
- Cleanroom Fans: 11%
- Process Utilities: 17%
- Other Misc.: 6%
- Cleanroom Lights: 1%

Cleanroom Programming

A hierarchy approach of information gathering for cleanroom programming
- Provides guidance on decisions during programming stage
- Reinforces that energy is an important consideration
Cleanroom Programming

Integrated process of decision-making by disciplines and owners is critical

- Example: Process, Mechanical, Electrical, and Architectural
  - Sizing systems: process, mechanical and electrical interface
  - Low pressure drop: mechanical and architectural interface
  - Airflow requirement: mechanical and controls

Cleanroom Programming

- Exemplar Concepts
  - Minimize clean space
  - Optimize cleanliness level
  - Optimize air change rate, ceiling coverage
  - Consider use of mini-environment
  - Minimize pressure drop
    - Location of large air handlers
    - Airflow path/space for low pressure drop
    - Airflow speed
Cleanroom Systems

- HVAC Air Systems
- HVAC Water Systems
- Power Systems
- Process Systems
- Cross-cutting & Misc. Issues
Recirculation Airflow

In-situ ISO Class 5 cleanroom air speeds and air change rates
Source: Xu 2004, Journal of the IEST

Recirculation Efficiency – SEMATECH
Projection of annual fan kWh cost (fans for air circulation) between year 2002 to 2020 for an 1,000,000 m³/h (or 583,000 cfm) Class 5 cleanroom
Source: Xu 2004, Journal of the IEST

Airflow speed at filter face is the airflow speed at location downstream of the face of the HEPA/ULPA filters
Intense power for re-circulating air

All Recirculation Air Handlers

A higher number of electric power intensity indicates lower delivery efficiency of the recirculation air system

Cleanroom Operation

- Reliability Improvement
  - Controls
  - Set points
- Maintenance
  - Leaks
  - Motors, pumps, Fans
  - Filters
  - Chillers, boilers, etc.
- Safety issues uncovered
  - Hazardous airflow
Example: Cleanroom Systems

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low pressure drop</td>
<td>Variable speed drive chillers</td>
<td>UPS systems</td>
<td>VOC abatement</td>
<td>Motor efficiency</td>
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<tr>
<td>Recirculation system type</td>
<td>Chilled water controls</td>
<td>Self generation</td>
<td>Minienvironments</td>
<td>Steam systems</td>
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<td>Air change rates</td>
<td>Cooling tower/condenser water optimization</td>
<td>Distribution</td>
<td>Vacuum pump optimization</td>
<td>Variable speed drives</td>
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<td>Demand controlled filtration</td>
<td>Water-side free cooling</td>
<td>DI water generation</td>
<td>Lighting</td>
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<td>Fan efficiency</td>
<td>Variable speed pumping</td>
<td>DI water reduction</td>
<td>Maintenance</td>
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<td>Fan-filter units</td>
<td>Duct temperature chilled water loops</td>
<td>Process chillers</td>
<td>Commissioning</td>
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<tr>
<td>Exhaust optimization</td>
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<td>Compressed air systems</td>
<td>Heat recovery</td>
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<tr>
<td>Exhaust systems</td>
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</tr>
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</table>

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Example: HVAC Air Systems

- **Goals**
  - Reduce initial costs
    - optimized sizing
  - Reduce utility costs while benefiting productivity
  - Other non-energy benefits
  - Energy efficient design can be considered as a strategy in the industry to achieve cost savings and improve bottom line
Example: HVAC Air Systems

- **Measures**
  - Low pressure drop
  - Recirculation system type
  - Air change rates
  - Demand controlled filtration
  - Fan efficiency
  - Fan-filter units
  - Exhaust optimization
  - Exhaust systems
Total Pressure Efficiency

Example: HVAC Water Systems

- **Measures**
  - Variable speed drive chillers
  - Chilled water controls
  - Cooling tower/condenser water optimization
  - Water-side free cooling
  - Variable speed pumping
  - Dual temperature chilled water loops
Example: Power Systems

- Measures
  - UPS systems
  - Self generation
  - Distribution

Example: Process Systems

- Measures
  - VOC abatement
  - Minienvironments
  - Vacuum pump optimization
  - DI water generation
  - DI water reduction
  - Process chillers
  - Compressed air systems
Presentation Coverage

• Sustainable development in cleanroom buildings
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• Examples

• Best Practice

Example: Cross-cutting & Misc. Issues

• Measures
  – Motor efficiency
  – Steam systems
  – Variable speed drives
  – Lighting
  – Maintenance
  – Commissioning
  – Heat recovery
  – Right-sizing
Considerations for Best Practice

<table>
<thead>
<tr>
<th>Considerations</th>
<th>Concepts and actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process Heat Load</strong></td>
<td><strong>Understand nameplate data which is nominal load information as compared to actual performance of the equipment</strong></td>
</tr>
<tr>
<td><strong>Name plate data</strong></td>
<td><strong>Understand actual load versus design conservatism</strong></td>
</tr>
<tr>
<td><strong>Electric load</strong></td>
<td><strong>Adopt efficient process equipment, transformer and UPS</strong></td>
</tr>
<tr>
<td><strong>Efficient operation</strong></td>
<td><strong>Understand efficiency of partial load and consideration of future expansion</strong></td>
</tr>
<tr>
<td><strong>Contamination Control</strong></td>
<td><strong>Understand and define the actual need for contamination control and define recirculation air change and/or airflow rate</strong></td>
</tr>
<tr>
<td><strong>Cleanliness classification</strong></td>
<td><strong>Optimize fan-speeds</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Define filter coverage</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Define filtration efficiency</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Define airflow uniformity requirements</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Analyze location impact of recirculation and exhaust</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Identify source of contamination</strong></td>
</tr>
</tbody>
</table>

To appear in IEST RP CC012.2 “Considerations for Cleanroom Design” 2007

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Considerations for Best Practice

<table>
<thead>
<tr>
<th>Considerations</th>
<th>Concepts and actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Make-up and exhaust requirements</strong></td>
<td><strong>Define and optimize airflow rate and airflow pattern</strong></td>
</tr>
<tr>
<td><strong>Optimal environmental requirements</strong></td>
<td><strong>Optimize humidity</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Optimize temperature</strong></td>
</tr>
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<td><strong>Define particle concentration</strong></td>
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<td><strong>Optimize pressure</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Optimize cascading</strong></td>
</tr>
<tr>
<td><strong>Recirculation air Systems</strong></td>
<td><strong>Adopt performance metrics such as electric power demand (Watt) per airflow rate component efficiency, e.g., fan-filter units</strong></td>
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<tr>
<td><strong>Optimal Efficiency</strong></td>
<td><strong>Optimize air management design</strong></td>
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<tr>
<td></td>
<td><strong>Define ranges of Air change and speed targets</strong></td>
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<td></td>
<td><strong>Aim at low pressure drop air handlers and systems uniformly</strong></td>
</tr>
<tr>
<td><strong>Space management</strong></td>
<td><strong>Layout and adjacency to primary cleanrooms</strong></td>
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<tr>
<td><strong>Optimal Airflows</strong></td>
<td><strong>Right size</strong></td>
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<td><strong>Optimize air management design</strong></td>
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<td><strong>Define ranges of Air change and speed targets</strong></td>
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<td><strong>Aim at low pressure drop air handlers and systems uniformly</strong></td>
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<td><strong>Optimal Filtration</strong></td>
<td><strong>Select filter media and resistance</strong></td>
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<td><strong>Define filtration efficiency</strong></td>
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<td></td>
<td><strong>Provide demand filtration control of particles</strong></td>
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<td><strong>Control with occupancy and scheduling</strong></td>
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<td><strong>Low-pressure drop</strong></td>
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## Considerations for Best Practice

### Considerations

<table>
<thead>
<tr>
<th>Make-up and Exhaust Systems</th>
<th>Concepts and actions</th>
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<tr>
<td>Optimal Efficiency</td>
<td>Right sizing</td>
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<td>Adjacency</td>
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<td>Duct layout</td>
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<td>Optimal placement, sizing, and filtration</td>
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<td>Duct integrity</td>
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<td>Component efficiency</td>
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<td>Variable speed drive</td>
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<th>Optimal Airflows</th>
<th>Code requirements</th>
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<td>Process diversification</td>
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<td>Heat exhaust</td>
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<td>Low pressure drop</td>
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<td>Layout of ducts</td>
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<td>Optimal airflow speeds</td>
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### Considerations

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<th>Cooled Water systems</th>
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<td>Optimal System efficiency</td>
<td>Chilled water temperature</td>
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<td>Use of “free cooling”</td>
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<td>Performance target for chillers and systems</td>
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<td>Control for partial load operation</td>
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<td>Efficient pumping</td>
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<td>Variable speed drive</td>
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<tr>
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<td>Adjacency and layout of major equipment</td>
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<td>Low pressure drop water system</td>
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<td>Process cooling</td>
<td>Alternatives to process refrigeration</td>
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<td>Non-compressive cooling</td>
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### Considerations for Best Practice

<table>
<thead>
<tr>
<th>Considersations</th>
<th>Concepts and actions</th>
</tr>
</thead>
</table>
| **Electrical systems** | Higher voltage  
Power factor  
Efficient power supplies  
Efficient lighting and controls  
Efficient UPS  
Efficient motors |
| **Optimal power efficiency** | Efficient process equipment  
Right-size  
Coordination with mechanical systems |
| **Optimal process load** | |
| **Control systems** | Protocol  
Monitoring  
Environmental control | Open  
Adequate capability  
Internet capability  
EMCS systems for power and airflow  
Humidity  
Temperature  
Particle  
Pressure |

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### Cleanroom Best Practice

- **Understanding Loads**
  - Contamination control
    - Process
    - Cleanliness level – ISO Std. 14644-1&2
  - Environmental requirements
    - Temperature
    - Humidity
    - Electrostatics
Cleanliness Classes

Table 1 — Selected airborne particulate cleanliness classes for cleanrooms and clean zones

<table>
<thead>
<tr>
<th>ISO classification number (N)</th>
<th>0.1 μm</th>
<th>0.2 μm</th>
<th>0.3 μm</th>
<th>0.5 μm</th>
<th>1 μm</th>
<th>5 μm</th>
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<td>ISO Class 1</td>
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<td>2</td>
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<td>ISO Class 2</td>
<td>100</td>
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<td>ISO Class 3</td>
<td>1 000</td>
<td>237</td>
<td>100</td>
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<td>8</td>
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<td>ISO Class 4</td>
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<td>2 370</td>
<td>1 020</td>
<td>363</td>
<td>83</td>
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<td>ISO Class 5</td>
<td>100 000</td>
<td>23 700</td>
<td>10 200</td>
<td>3 520</td>
<td>832</td>
<td>29</td>
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<td>ISO Class 6</td>
<td>1 000 000</td>
<td>237 000</td>
<td>102 000</td>
<td>35 200</td>
<td>8 320</td>
<td>293</td>
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<td>ISO Class 7</td>
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<td>352 000</td>
<td>63 200</td>
<td>2 930</td>
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<td>ISO Class 8</td>
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<td>3 520 000</td>
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<td>35 200 000</td>
<td>8 320 000</td>
<td>293 000</td>
</tr>
</tbody>
</table>

NOTE: Uncertainties related to the measurement process require that concentration data with no more than three significant figures be used in determining the classification level.

ISO 14644-1 cleanliness classes

Cleanroom Best Practice

- Reducing/optimizing Loads
  - Demand control filtration
  - Sizing
  - Airflow
  - Filtration
  - UPS
  - More…
Cleanroom Best Practice

• Reducing/optimizing Loads
  – Demand control filtration
    • Power-down
    • Setback
    • Particle counting

Cleanroom Best Practice

• Reducing/optimizing Loads
  – Sizing
    • Cooling
    • AHU
    • Cleanroom vs. Minienvironment
Cleanroom Best Practice

- Reducing/optimizing Loads
  - Airflow
    - Recirculation type
    - Recirculation Airflow rates – Air change rate
    - IEST RP12
    - ISO Std. 14664
Cleanroom Best Practice

- Meeting the Load
  - Chiller plant optimization
  - Right sizing
  - Economizer
  - Cooling tower
  - AHU
  - Air distribution
  - Heat exchanger
  - Self or Co-generation

Cleanroom Best Practice

- Chiller plant optimization
  - Chiller specification
  - Chiller Types
    - Air cooled vs. water cooled
    - VSD centrifugal vs. constant
Cleanroom Best Practice

- **Chiller plant optimization**
  - Operation and control of chilled water
  - **Principles:**
    - A larger lift of chilled water temperature makes chilled water system less efficient
    - A higher chilled water supply temperature improves efficiency

---

Cleanroom Best Practice

- **Chiller plant optimization**
  - Operation and control of chilled water
  - **Rule of thumb:**
    - For a centrifugal compressors-based chiller, an increase of one degree in the chilled water supply temperature improves the efficiency of the chiller by 1 to 2%.
  - **Approaches**
    - chilled water temperature reset
    - differential pressure setpoint reset
Cleanroom Best Practice

- **Chiller plant optimization**
  - Operation and control of chilled water
    - Approaches
      - chilled water temperature reset
        - CHW temperature based on the outside air temperature
        - Chilled water valves in the loop at full position
        - Reduce CHW temperature only when all valve is open 90% or more
      - differential pressure set point reset

- **Chiller plant optimization**
  - Operation and control of chilled water
    - Approaches
      - differential pressure set point reset
        - save power for pumping water
        - based on the cooling valve positions
        - differential set point can be reduced when valve opening decreases
        - Coil to be oversized
Best practices

Consideration of Sizing of air systems
- Minimize clean space
- Correct classification for contamination problem
- Air change rate
- Minimize pressure drop
- VFD's can help
- Exhaust minimization

Best Practices

Factors affecting air flow resistance
- duct size (oversized is good)
- low face velocity
- minimize length of duct/air path
- efficient, low pressure drop filters
- raised floor air resistance (% open)
- size and placement of return air chases
- Use of plenums
Recirculation Setback

- Based solely on Time: 8:00 PM-6:00 AM setback
- No reported problems or pushback
- 60% – 70% power reduction

Recirculation Setback

- **Annual Fan Savings from Daily and Weekend Setback:**
  - 1,000,000 kWh
    $130,000 - $150,000

- **Cooling load reduction when setback:**
  - 120 kW
    35 tons
Energy-Savings Opportunities

- **Chiller**
  - Air-cooled chiller at 1 kW/ton, partially to conserve water
  - Water reuse for tower makeup (2,500 – 4,000 gallons/day rejected to sewer)

- **Space humidity control**
  - Energy intensive dehumidification/reheat
  - Exceeds design and process requirements
  - Reset humidity set-points to design

- **Fan power savings**
  - Control recirculation setback
  - Reduce air change rates

Demand Controlled Filtration

- Demand filtration based on real-time particle concentration measurements

- Fan power proportional to the cube of the flow rate, so small changes can result in large savings
Controlling Air Flow to Maintain Cleanliness

- Save energy by reducing fan speeds without degrading conditions in cleanroom
- Reduction of recirculation fan speed during unoccupied periods or periods of no activity (potential for mini-environments also)

Recirculation Setback

- Based solely on Time: 8:00 PM-6:00 AM setback
- No reported problems or pushback
- 60% – 70% power reduction
Industry Collaboration Essential for sustainable development

- LBNL
- IEST (mini-environment, fan-filter units)
- Sematech
- Silicon Valley Manufacturers Group
- ITRI (Industrial Technology Research Institute, Taiwan)
- Air Movement and Control Association (AMCA)
- ASHRAE

Recommended Practice

- LBNL Standardized method to
  - Produce comparable performance information and identifies most efficient and functional FFUs
  - Stimulate design and applications of energy efficient FFUs
- IEST CC RP036.1 – testing fan filter units
  - Working draft of RP036.1
  - Web Board participation in RP development
Questions