Enhancement of Air Quality in Clean Rooms

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Introduction
Definition of a Clean Room

According to ISO 14644 (1999), a clean room is 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 & microbes inside the room and in which other relevant parameters, e.g. temperature, humidity, and pressure, are controlled as necessary.
**Airborne Particles**

- People in the work space generate particles in the form of skin flakes, lint, cosmetics, and respiratory emissions.
- A human hair is about 75-100 microns in diameter. A particle 200 times smaller (0.5 micron) than the human hair can cause major disaster in a clean room.
Particles Sources

**External Sources**

- Infiltration through doors, windows and wall and ceiling penetrations.
- Outside makeup air entering through the air conditioning.
- Controlled primarily by air filtration, room pressurization and sealing of space penetrations.

**Internal Sources**

- People, clean room surface shedding, process equipment and the manufacturing process itself.
- Controlled with new clean room garments, proper gowning procedures and airflow designed to continually shower the workers with clean air.
Particle generation rate for persons

People are the major source of contamination in the clean room released from skin flakes and oil, hair, spittle, cosmetics & perfume, clothing debris.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>*PARTICLES</th>
<th>DESCRIPTION OF ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100,000</td>
<td>MOTIONLESS IN EITHER SITTING OR STANDING POSITION</td>
</tr>
<tr>
<td></td>
<td>500,000</td>
<td>HANDS, FOREARMS, NECK AND HEAD MOTION</td>
</tr>
<tr>
<td></td>
<td>1,000,000</td>
<td>HANDS, ARMS, TRUNK, NECK, HEAD MOTION AND SOME LOWER BODY MOTION</td>
</tr>
<tr>
<td></td>
<td>2,500,000</td>
<td>SITTING TO STANDING OR VICE VERSA</td>
</tr>
<tr>
<td></td>
<td>5,000,000</td>
<td>WALKING AT 2.0 MPH</td>
</tr>
<tr>
<td></td>
<td>7,500,000</td>
<td>WALKING AT 3.5 MPH</td>
</tr>
<tr>
<td></td>
<td>10,000,000</td>
<td>WALKING AT 5.0 MPH</td>
</tr>
</tbody>
</table>

Source:-(Austin and Timmerman 1965).
Airborne Particulate Cleanliness Classes

Define the maximum number of airborne submicron particles measured in volume unit (cubic foot (ft³) or cubic meter (m³)) of air.

<table>
<thead>
<tr>
<th>Class</th>
<th>( \geq 0.1 \mu m )</th>
<th>( \geq 0.2 \mu m )</th>
<th>( \geq 0.3 \mu m )</th>
<th>( \geq 0.5 \mu m )</th>
<th>( \geq 1 \mu m )</th>
<th>( \geq 5 \mu m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 1</td>
<td>10</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 2</td>
<td>100</td>
<td>24</td>
<td>10</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 3</td>
<td>1,000</td>
<td>237</td>
<td>102</td>
<td>35</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>ISO 4</td>
<td>10,000</td>
<td>2,370</td>
<td>1,020</td>
<td>352</td>
<td>83</td>
<td>83</td>
</tr>
<tr>
<td>ISO 5</td>
<td>100,000</td>
<td>23,700</td>
<td>10,200</td>
<td>3,520</td>
<td>832</td>
<td>832</td>
</tr>
<tr>
<td>ISO 6</td>
<td>1,000,000</td>
<td>237,000</td>
<td>102,000</td>
<td>35,200</td>
<td>8,320</td>
<td>8,320</td>
</tr>
<tr>
<td>ISO 7</td>
<td></td>
<td>352,000</td>
<td>83,200</td>
<td>2,930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 8</td>
<td>3,520,000</td>
<td>832,000</td>
<td>29,300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 9</td>
<td>35,200,000</td>
<td>8,320,000</td>
<td>293,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Federal standard equivalent to ISO standard
Objectives

• Using CFD as a tool to simulate the particles concentration distribution considering people are the main source of airborne particles in a clean room constructed for electronics industry. Besides, studying velocity, temperature and humidity distribution and making a comparison with measurements.

• Studying the effect of placement variation of inlet and exit of air flow by proposing different designs.

• Simulation of the particles concentration in the case of there is a pressure difference between the air pressure inside the main room and the air pressure inside the gowning room.
Description of the Clean Room Existing
Existing design of the clean room

- Gowning Room
- Main Room
- Air Shower Room
Air Shower Room

- Inlet Door
- Exit Door
- Air Inlet
- Air Exit
Gowning Room

Gowning board

Door

Door
Numerical Modeling
CFD Modeling

Standing human model

Seating human model
CFD Modeling

Simulation of human seating while working on the working bench
The total number of nodes in the volume was 1198276 nodes.
Boundary Conditions

Room Walls
Temperature of the floor is assumed to be 24°C, and remaining walls are assumed to have a temperature of 25°C (measured).

Inlet Air Conditions For Original Case
Air enters with 0.45 m/s ( = 15 ACH (air changes per hour)) and temperature of 23°C (measured), humidity of 63 % (measured).

Boundary Conditions of Occupant's bodies and faces (heat source and H₂O source)

• The mass flow or expired air from the occupants is calculated as 2*10⁻⁴ kg/s per occupant based on 20 times per minute, Schottelius (1978), during normal activity.

• The volume of the H₂O gas in the expired air from occupant is 6.2% of the total volume of the expired air.

• The occupant's bodies as obstacles, having a temperature of 37 °C, Guyton (1986), and heat generation rate based on occupant's activity.
Airborne particles generation from persons

<table>
<thead>
<tr>
<th>Activity</th>
<th>Underpants (particles/min)</th>
<th>Cleanroom garment (particles/min)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting still</td>
<td>40,000</td>
<td>40,000</td>
<td>1.0</td>
</tr>
<tr>
<td>Sitting: arm movements</td>
<td>90,000</td>
<td>70,000</td>
<td>1.3</td>
</tr>
<tr>
<td>Standing: rotation torso</td>
<td>140,000</td>
<td>60,000</td>
<td>2.0</td>
</tr>
<tr>
<td>Walking on the spot</td>
<td>400,000</td>
<td>180,000</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Particle strength from person (particles /minute)

Source: Ramstorp et al. (2005)
The measured concentration (µg/m³) of generated particles with time during soldering process
Proposed Design Configurations
1st proposed design

- 36 Inlet Grilles
- 10 Lamps
- 16 Exhaust grilles on this side
- 10 Exhaust grilles on this side
2nd proposed design

Air Inlet from the entire ceiling

10 Lamps

16 Exhaust grilles on this side

10 Exhaust grilles on this side
Experimental Work
The locations at which measurements were taken

- At each line, measurements were taking at \( y = 1 \text{ m}, \ y = 1.5 \text{ m}, \ y = 2 \text{ m} \)
Velocity and Temperature Measurement

Hot film thermal anemometer
(accuracy of ±3%)

• Measurements were taken as the average of three successive readings due to turbulence and fluctuations of the air flow.
Airborne Particles Concentration Measurements

- The Pdr-1500 covers a wide measurement range from 0.001 mg/m³ to 400 mg /m³ with an accuracy of ± 5% corresponding to very clean air up to an extremely high aerosol concentration.

- All particle measurements were done on two stages, the first stage with particles diameter range from 1 µm to 4 µm, and the second stage with particles diameter range from 4 µm to 10 µm. This was done by changing the filter of the instrument before turning on the device.

- This device is used mainly for particles concentration measurement but it also used for temperature and relative humidity measurements. The measuring range is from 0 to 100% RH with a resolution of 0.15 % RH and accuracy up to 1% RH.
Results
Sample of the numerical prediction versus measurements

- Velocity (m/s) at line (5)
- Particles Concentration (µg/m³) at line (10)
Existing versus proposed designs

For the existing design

- 21 lighting units
- 10 inlet air grilles
- 9 exhaust air grilles

For the 1st proposed design

- 36 exhaust air grilles
- 10 lighting units
- 16 exhaust air grilles on this wall side
- 10 exhaust air grilles on this wall side

For the 2nd proposed design

- Air inlet
- 10 lighting units
- 16 exhaust air grilles on this wall side
- 10 exhaust air grilles on this wall side
Path lines of the inlet air colored by velocity magnitude

For the existing design

For the 1st proposed design

For the 2nd proposed design
Temperature contours (K) at y = 1 m

For the existing design

For the 1st proposed design

For the 2nd proposed design
Airborne particles concentration (µg/m³) at y = 1 m

For the existing design

For the 1st proposed design

For the 2nd proposed design
Path lines of the contaminant particles colored by the concentration (µg/m³)

For the existing design

For the 1st proposed design

For the 2nd proposed design
Conclusions

• The use of complete unidirectional air flow (ceiling supply) in the clean room makes the airborne particles distribution to be ideal, as it prevents turbulence and unites the air direction to be down pushing particles to move towards floor leaving workers body and working benches.

• It is very important to use CFD as a tool to predict air flow patterns at different ACH in order to select the suitable ACH knowing that the present study as well as the most recent studies recommended that a minimum of 20 ACH is required in clean rooms.

• Soldering emissions have random directions for the original case due to turbulence but in the 1st configuration the number of air inlets were increased that leaded to forcing the emissions to move away from persons. In the 2nd configuration, the air displaces emissions to move downward with the flow direction from the entire ceiling. In the 3rd configuration, emissions moved towards hoods due to air suction force in the hoods.

• Making the clean room pressurized with air pressure in the main room higher than the adjacent gowning room by a $\Delta p = 10 \text{ pa}$ prevented air particles from the transportation from outside into the room during door opening.