High Efficiency Particulate Air (HEPA) Filter Velocity Reduction Study

International SEMATECH Manufacturing Initiative
Technology Transfer #06084775A-TR

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Abstract: This document describes a study conducted at a SEMATECH member company facility to determine whether high efficiency particulate air (HEPA) filter velocity (airflow) could be minimized without affecting fab operation. Eighteen sets of instrumental data were collected at the baseline operating condition and then again at the lowered HEPA velocities. The data were compared to determine differences in cleanroom performance at different HEPA velocities.

Keywords: Air Flow, Energy Use Reduction, Cleanroom Parameters, Air Filters

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1 EXECUTIVE SUMMARY

Recirculation air systems are significant consumers of electrical power in a wafer fab. Therefore, it would be advantageous to minimize high efficiency particulate air (HEPA) filter velocity (airflow) as long as it does not impact fab operation. Wafer yield is the best measure of a change in operational parameters, but a reduction of HEPA velocity can also be characterized by the study of selected cleanroom parameters.

A study was conducted at a SEMATECH member company facility where HEPA filter velocity was decreased. Eighteen sets of instrumental data were collected at the baseline operating condition and then again at the lowered HEPA velocities. The data were compared to determine differences in cleanroom performance at different HEPA velocities. The findings were as follows:

1. Details of the air velocity measurement must be provided when stating HEPA filter velocity. Different instruments and techniques report different values.
2. Reduced HEPA velocity had no practical effect on differential pressures, sound pressure levels, airflow parallelism, temperature, and relative humidity (RH).
3. Reduced HEPA velocity levels maintained the area’s specified airborne particulate class, although there was an increase in both the number of particles and variation of counts. In areas with air ionization, lower HEPA velocity increased the mean time to drain a surface charge. There was a statistical increase in the total adsorbed vapors on a silicon oxide surface at the lower air velocities.
4. The mechanical power consumption of the recirculation air system is proportional to the cube of the volumetric airflow. Recirculation air handling systems operating at design capacity exhibited significant and predictable energy savings at the lower HEPA velocity. For recirculation units operating below capacity conditions, no energy savings were obtained with the lower recirculation airflow rate.

2 THEORETICAL REVIEW – SEMICONDUCTOR FACILITY AIR SYSTEMS

The largest energy consumers in the typical microelectronic facility are the process equipment, the recirculation air handlers, the make-up air (fresh air) production, and the ultrapure water (UPW) production.

The selected equipment affects both capital investment as well as operating costs of advanced wafer fabs. A considerable portion of the initial fab cost is driven by the fundamental concepts underlying the operational aspects of the facility and the quality level of various components and subsystems. Furthermore, the type of cleanroom design used, especially the type of recirculation air system, is responsible for a significant amount of the total operational energy costs. This section deals specifically with cleanroom air concepts including the energy consumption of recirculation systems.

The power demand (N) of the recirculation fan can easily be approximated from the airflow (V), the pressure drop (Δp), and the fan efficiency (η) (combined) by the equation:

$$N = \left(V * \Delta p\right) / \eta$$

The required recirculation airflow volume depends on the cleanroom area and the required cleanroom class. The airflow volume is a direct consequence of the required HEPA filter face velocity. However, the recirculating air system pressure drop and the efficiency of the fans can be optimized by carefully matching the design of the recirculation system with the fan characteristics. The pressure drop of the recirculation system is determined by the HEPA filters, pre-filters, sound attenuators, heat exchangers, the cross-sectional areas, and the design of turns along the airflow path.

The fan laws are another useful tool. These simple relationships relate fan capacity, pressure, speed, and power. The fan laws are useful in establishing boundaries on possible savings with different operating conditions:

- The airflow volume is directly proportional to the fan speed ; $Q1/Q2 = (rpm_1/rpm_2)$
- The pressure (static, total, or velocity) is proportional to the square of the fan speed; $P_1/P_2 = (rpm_1/rpm_2)^2$
- The power required is proportional to the cube of the fan speed: $W_1/W_2 = (rpm_1/rpm_2)^3$
- The pressure and power are proportional to the density of the air at constant speed and airflow
- Speed, airflow, and power are inversely proportional to the square root of the density at constant pressure

Reducing HEPA filter velocity will reduce energy consumption if the recirculation system is operating in the appropriate efficiency range (η) for the combination of fan, motor, system, and electronic control. If the fan system is within the correct parameters, energy savings can be quite significant.

In general, three basic types of air supply and recirculation systems are currently used in a semiconductor cleanroom:

1. Recirculation Air System with Compact Air Handling Units (RAHUs) Located Above the Ceiling Grid

   The air is supplied by ducts to a pressurized plenum or to filter hoods (see Figure 1). The design is typically determined by a selection of standardized housing elements and components, characterized by small cross sections that are often combined with several internal turns, thereby creating high pressure drops. Increased overall building height is needed for the installation of the units as well as a cooling water supply above the ceiling grid.

2. Recirculation Air System with Fan Towers

   Large vane axial fans are located in return airshafts on both opposite walls of the cleanroom level. The same applies for the return air level. The air is supplied by a pressurized plenum to the ULPA filters (see Figure 2). Large cross sections and low air velocities as well as only one elbow turn on both the inlet and discharge side of the return airshaft characterize the system.

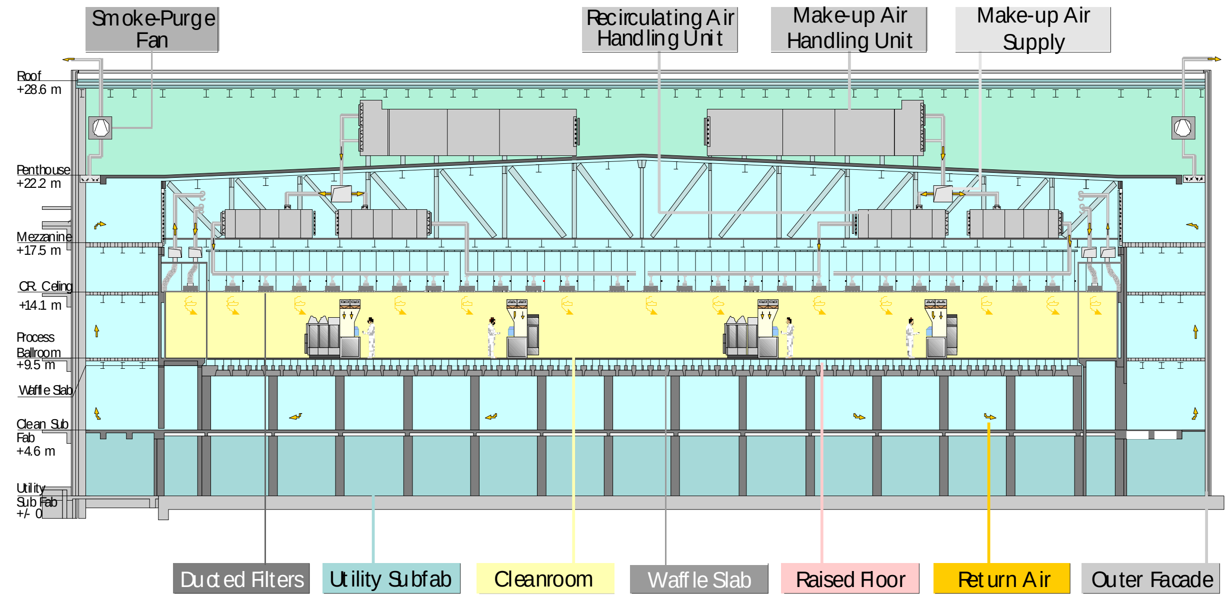

Figure 1 Cross Section of a Fab with Compact Air Handling Units as Recirculation Air System

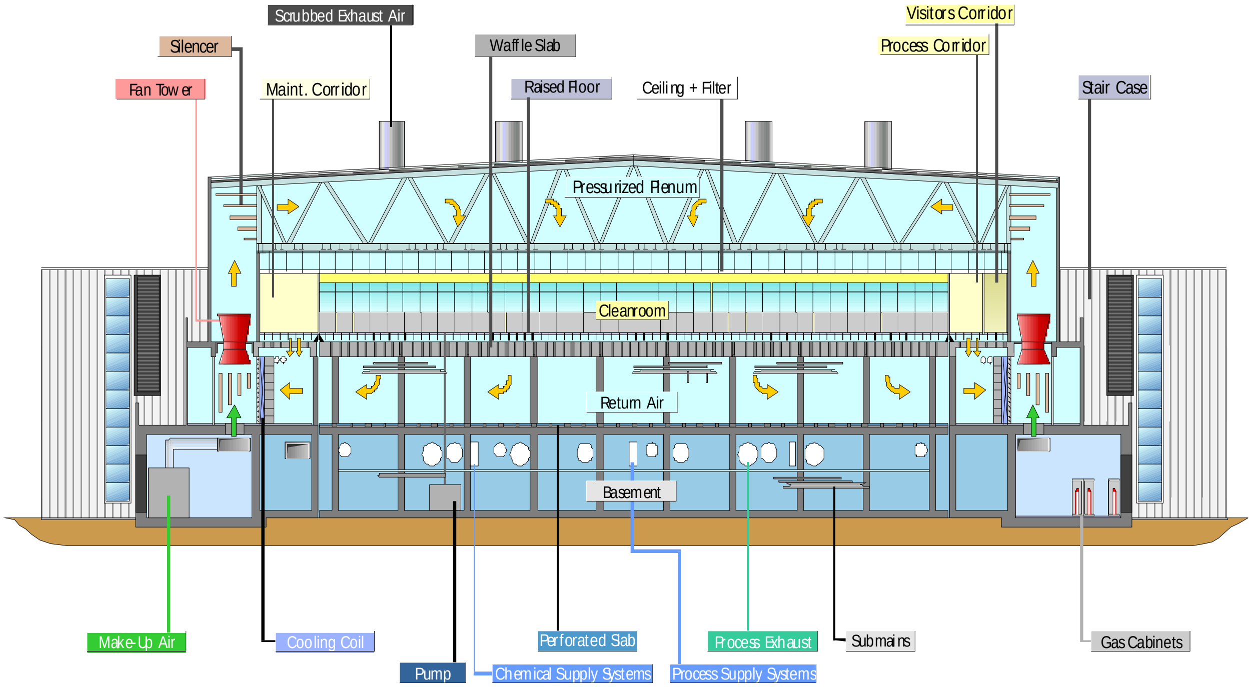

Figure 2 Cross Section of a Fab with Fan Towers as Recirculation Air System

3. Recirculation Air System with Filter Fan Units (FFUs)

   FFUs are compact modules directly installed in the ceiling grid (see Figure 3). This offers high flexibility for the cleanroom design (zoning, segregation, placement of walls, etc.). The recirculation air flows through cooling coils to the return airshafts. The plenum above the ceiling grid is non-pressurized.

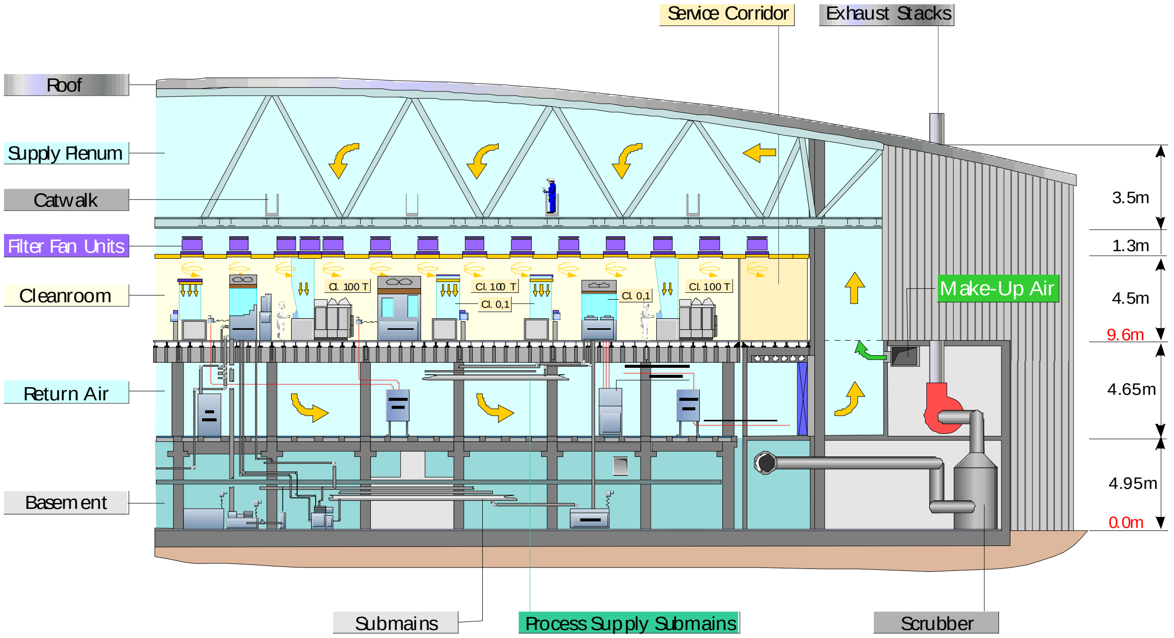

Figure 3 Cross Section of a Fab with FFUs as Recirculation Air System

2.1 Energy Consumption

For a given amount of airflow the energy consumption of recirculation air systems depends on the total pressure drop and the fan system efficiency. Figure 4 shows a survey of the resulting power demand of different recirculation air systems used in cleanroom projects related to 10.8 ft^2 (1 m^2) of ULPA filter area at assumed 90 feet per min. (fpm) or 0.45 meters per sec. (m/s) discharge air velocity. Although high efficiency radial fans are commonly used in compact air handling units, the resulting power demand is high. Improved fan efficiency does not compensate for the losses caused by the high system pressure drop.

Well designed advanced fan towers and FFU systems can meet the requirements for further reduction of energy consumption. In the case of fan towers, a moderate overall system pressure drop and high fan efficiency result in lower power consumption. In the case of FFUs, the power-saving effect of the low system pressure drop dominates the effect of the moderate efficiency of the small fans. This results in similar power consumption rates for both cases. When a minienvironment is used instead of a bay and chase, the total recirculation airflow energy consumption can be reduced to less than 40% for each of the systems. This is because of the dramatic reduction of airflow.

In addition to the power demand of the fan itself, the power demand of the chiller, which is needed to remove the cleanroom heat load caused by the different systems, is to be considered.

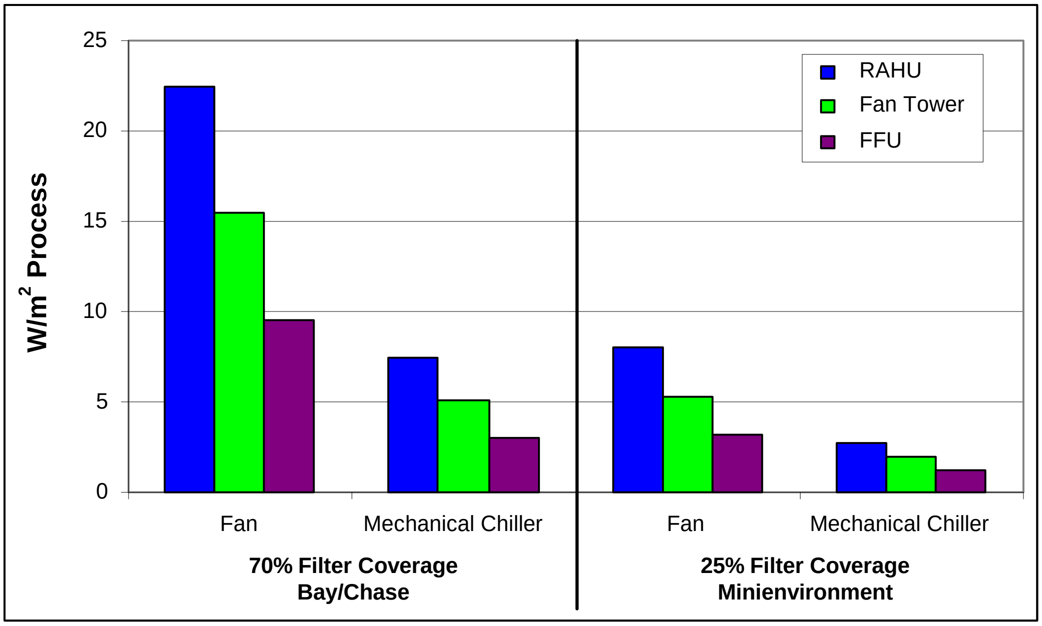

Figure 4 Power Consumption of Different Recirculation Air Systems

In terms of initial costs, the fan tower system combined with the pressurized plenum may be the preferred solution for large ceiling grids with high filter coverage. The limited number of large units results in low specific costs despite the disadvantage of using pressurized and more expensive ceiling grids. Considerable operating cost savings may be achieved by using well-designed advanced recirculation air systems like fan towers or filter fan units.

Filter fan units in general cause additional costs for electrical supply, control, and monitoring. Because no pressurized ceiling grid is needed, these disadvantages may be equalized or even overcome when smaller rates of ceiling filter coverage (e.g., minienvironment cleanroom) are used. The advantage comes to light when smaller cleanroom areas are used. An additional important advantage is the reduced time schedule for the overall cleanroom installation and start-up procedure. Because standardized units are used, the timeframe for design and construction is drastically reduced. Recirculation air systems based on conventional air handling units or even fan towers require significantly longer timeframes.

3 DESCRIPTION OF MEASUREMENTS

Multiple instruments and procedures were used to collect the data for this study.

Table 1 and Table 2 summarize each measurement type. Spot measurements and continuous measurements were performed.

Table 1 Summary of Spot Measurements of Room Conditions

	Type of Sample	Test Area in Diffusion	Test Area in Photolithography	Treatment of Data	Field Calibration to Determine Instrumental Offset?
Electrical power consumption of rooftop air handlers	Meter reading of steady state value	2 air handlers	7 air handlers	Mean and Std. Dev.	No
Recirculation airflow – total supply to room	Flow grid	2 air handlers	7 air handlers	Average totalized flow	No
RAH sensible coil chilled water flow	Contact spot measure	2 air handlers	2 air handlers	Mean and Std. Dev.	No
RAH sensible coil chilled water supply and return	Direct – Pete's plug	2 air handlers	2 air handlers	Mean and Std. Dev.	
HEPA filter velocity	Spot reading at accessible locations in the room	56 – 2'x4' filters	455 – 2'x4' filters	Each discrete reading is average, report mean and Std. Dev.	Comparison with hot wire, anemometer, flow totalizer
Room classification	Particles per cubic foot sample at accessible locations	450 ft^2 room 42 m^2	3,640 ft^2 room 338 m^2	per 209	Verify zero with calibration filter
Parallelism	Measure deflection from center	450 ft^2 room 42 m^2	3,640 ft^2 room 338 m^2	Mean and Std. Dev.	
Sound pressure reading	Spot measure over uniform area distrib.	450 ft^2 room 42 m^2	3,640 ft^2 room 338 m^2	Location report of value	No
Room pressurization	Spot measure at room interfaces	aisle to chase, aisle to surround, chase to surround	ballroom to surround	Location report of value	Zero calibration prior to sample
Temperature	Spot measure over uniform area distrib.	450 ft^2 room 42 m^2	3,640 ft^2 room 338 m^2	Location report of value	Bundled probes in high flow area
Humidity	Spot measure over uniform area distrib.	450 ft^2 room 42 m^2	3,640 ft^2 room 338 m^2	Location report of value	Bundled probes in high flow area

Table 2 Summary of Continuous Measurements of Tool Specific Area

	Type of Sample	Test Area in Diffusion	Test Area in Photo Area	Treatment of Data	Field Calibration to Determine Instrumental Offset?
Temperature	Fixed location with data logger	4 points	4 points	Mean and Std. Dev.	Bundled probes in insulated box, label relative offsets
Humidity	Spot measure over uniform area distribution	4 points	4 points	Mean and Std. Dev.	Bundled probes in insulated box, label relative offsets
Electrostatic charge (ESC) decay	Charge plate and time the decay – spot measurement at fixed location	No ionizers	Ionizers	Time rate of decay	No
Airborne particle counts	Particles per cubic foot sample at two accessible locations	2 locations	2 locations	Mean and Std. Dev.	Verify zero with calibration filter
Surface particle counts	Pre- and post- exposure mapped counts	Settling wafers	Settling wafers		Repeated counts of wafers not removed from scan tool area
Surface particle counts	Simulated tool load and unload with travel	Load tool	Load tool		Repeated counts of wafers not removed from scan tool area
Molecular deposition	All volatile species settling rates	One location in chase	One location at load port	Beat frequency transformed to molecular arrival rate	No

4 CONCLUSIONS – HEPA VELOCITY REDUCTION STUDY

The measured values for HEPA filter velocity varied significantly because of the instrumental measurement technique. Physical variation in the facility configuration also affects the measurement. Whenever examining HEPA filter velocity and possible velocity reductions, detailed descriptions of the measurement technique and the facility are required for a reasonable comparison between different facilities.

The HEPA filter velocity condition at 90 fpm (0.45 m/s) exhibited significantly less airborne particles than 70 fpm (0.35 m/s); however, both conditions were within stated class limits. The variation in particle counts was lower at 90 fpm (0.45 m/s) than at 70 fpm (0.35 m/s).

HEPA velocity reduction from 90 fpm (0.45 m/s) to 70 fpm (0.35 m/s) had no practical effect on the differential pressure, sound power levels, airflow parallelism, static discharge, temperature and relative humidity.

SAW data indicate a statistical difference between total adsorbed vapors with lower levels of adsorption at the higher velocity.

For some of the air handlers examined in this study, a measured power consumption decrease was observed at the lower HEPA filter velocity. The measured decrease in power usage closely corresponds to the decrease predicted by the fan laws. Other air handlers examined in this study did not exhibit decreased power consumption at the decreased airflow. These units were known to operate well below design capacity. To achieve the desired recirculation fan energy savings, the recirculation system must be operating at the optimal point on the fan curve.

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