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Best Practices for Energy Efficient Cleanrooms: Minienvironments

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Summary

Cleanroom air-recirculation systems typically account for a significant portion of the HVAC energy use in cleanrooms. High electric power density is normally required for fans to deliver large volume of airflows that were designed, supplied, recirculated, and exhausted within a given time. With the increasing demand for specific contamination control, it is important to optimize design of clean spaces. Best practice in cleanroom air system design includes right-sizing the systems in cleanrooms and adopting minienvironments. Implementing and integrating minienvironments in cleanrooms can improve contamination control and save significant energy.

Principles

A minienvironment is a localized environment created by an enclosure to isolate a product or process from the surrounding environment. The advantages in using minienvironments include the following:

1) Minienvironments may create better contamination control and process integration.

2) Minienvironments may maintain better contamination control by better control of pressure difference or through use of unidirectional airflows, e.g., cleanliness-class upgrade required for certain process.

3) Minienvironments may potentially reduce energy costs.

The use of fan-filter units (FFU) in minienvironments is common. The energy efficiency of such air-delivery systems can vary significantly because of the difference in energy performance, airflow paths, and operating conditions. Simply adding minienvironments with fan-filter units in an existing cleanroom will increase power density and energy intensity for delivering airflow in the space served, if everything else is unchanged. However, by considering contamination control requirements in the various spaces minienvironments can be integrated with the surrounding cleanroom to optimize the overall electric power demand for the facility and to achieve specific cleanliness in each area. In addition, selecting energy efficient minienvironment systems will further improve the overall energy efficiency of the clean spaces.

Approach

Although minienvironments are becoming more popular, their energy and airflow performance can vary significantly. Owners, designers, suppliers and operators need to best use resources to determine the adoption of minienvironments, their integration with surrounding cleanroom spaces, and optimize the design, control, and installation of the minienvironments. Best practice with regard to improving energy efficient cleanrooms and minienvironments includes the following:

- Determine the cleanliness requirements for contamination control for both minienvironments and the surrounding cleanroom. For example, cleanliness levels do not need to be more stringent than the process occurring in the cleanroom requires.

- Use computation-fluid-dynamics (CFD) modeling and particle-count monitoring or experiment to assist in the design process.

- Determine the airflow velocities as well as air-change rates. Using optimal air-change rates will allow designers to lower construction costs as well as to reduce energy costs while maintaining the high level of air cleanliness that is required in cleanroom facilities. Often in minienvironments, what is needed is a positive pressure relative to the surrounding spaces and high airflows through the minienvironment are not necessarily required.

- Improve efficiency of the minienvironment systems and design, including using energy efficient fan-filter units and better controls.

- Optimize airflow rates of the surrounding cleanroom areas and where possible, reduce airflow rates whenever feasible.

Case Studies

Performance data from a case study on one minienvironment suggests that within the range of airflow speeds measured, the electric power density (in W/ft^2) of a minienvironment generally increased with the increase of airflow speeds (Figure 1). This trend was affected by the operating performance of the controller and the airflow rates. For example, the electric power density reached a maximal value when the airflow speed of the FFU reached 95 fpm, and it decreased with the increase of airflow speeds beyond 95 fpm while inside its operating range (Figure 1). Performance data from a case study on five operating minienvironments suggests that within the range of airflow speeds measured (50 fpm - 100 fpm), the electric power density of these minienvironments typically increased with the increase of airflow speeds within each minienvironment (Figure 2).

Corresponding to the operating airflow speeds that ranged from 50 fpm to 100 fpm, and power density of the minienvironments ranged from 26 W/ft^2 to 32 W/ft^2 with an average of 28 W/ft^2 (Figure 2). Lower power density generally indicates better energy performance to achieve the desired cleanliness within the minienvironments.

Best practice should consider implementing minienvironments in cleanrooms during planning and design stages of a project, whenever such an option presents a good solution to contamination control. Because of the much smaller minienvironment volume compared to that of full-scale cleanrooms (e.g., ballroom), the airflow rate and the electric power required for a minienvironment can be significantly reduced. Furthermore, lowering electric power density in cleanrooms, by integrating minienvironments will significantly reduce energy use for the whole facility. In the case study, power density of air-recirculation systems in the ISO Class 4 cleanroom was measured as 10 W/ft^2, in which a number of minienvironments were located (Figure 2). This was lower compared to the group of ISO Cleanliness Class 4 cleanrooms with a range of 16 to 38 W/ft^2 in a previous study (Xu 2004). In summary, in order to create opportunities for a significant overall energy savings, best practice should include measures to reduce fan power for both minienvironments and the cleanrooms that contain them. Reducing the fan power density as well as optimize floor area of the minienvironments and cleanrooms will lead to overall energy savings. Specifically, best practice to reduce electric power density of minienvironments may include the following

- Optimize (e.g., reduce) the airflow speeds and/or pressure inside the minienvironment.
- Improve the energy efficiency of the air systems, e.g., choose an efficient FFU, for the minienvironment.

In addition, as part of integrating minienvironments to cleanroom spaces, best practice to reduce overall electric power density is to reduce power density of the primary cleanroom surrounding the minienvironments. The following enlist some of the best practice approaches:

- Optimize airflow rates and air-change rates, e.g., reduce airflow speeds in the cleanroom.
- Select the right type and size of air-handling unit for recirculation.
- Optimize exhaust and make-up air systems.
- Adopt variable-speed-drive motors in air systems.
- Minimize system resistance.

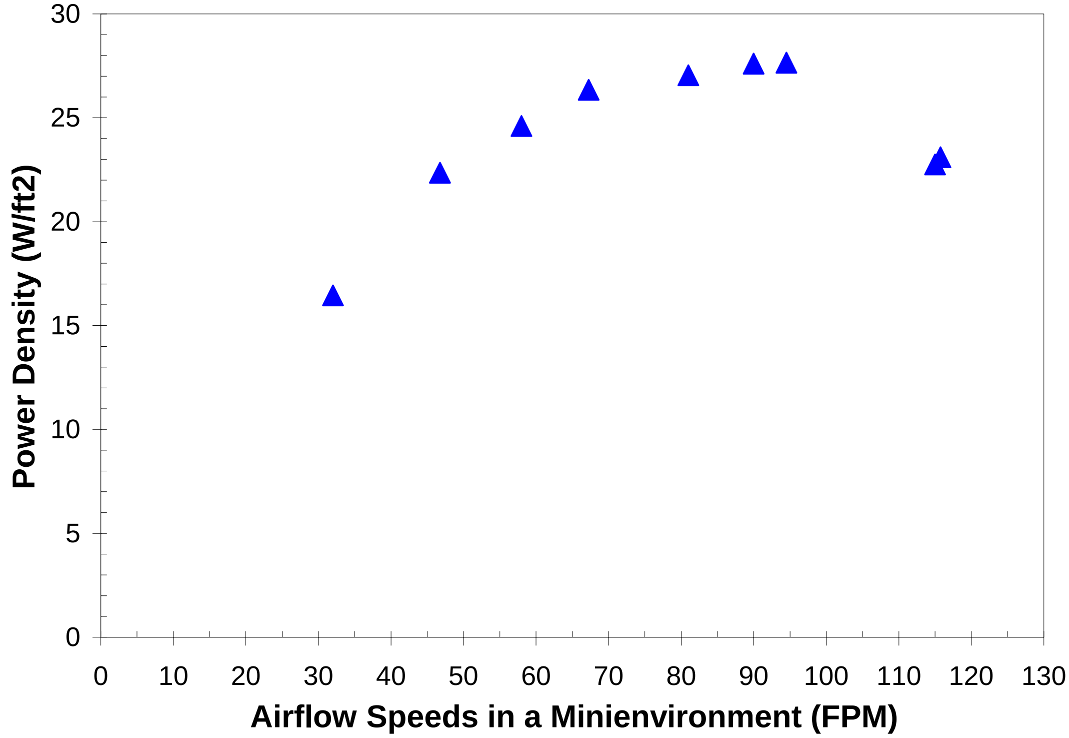

Figure 1. Power Density and Airflow Speeds for a Minienvironments under Different Operation

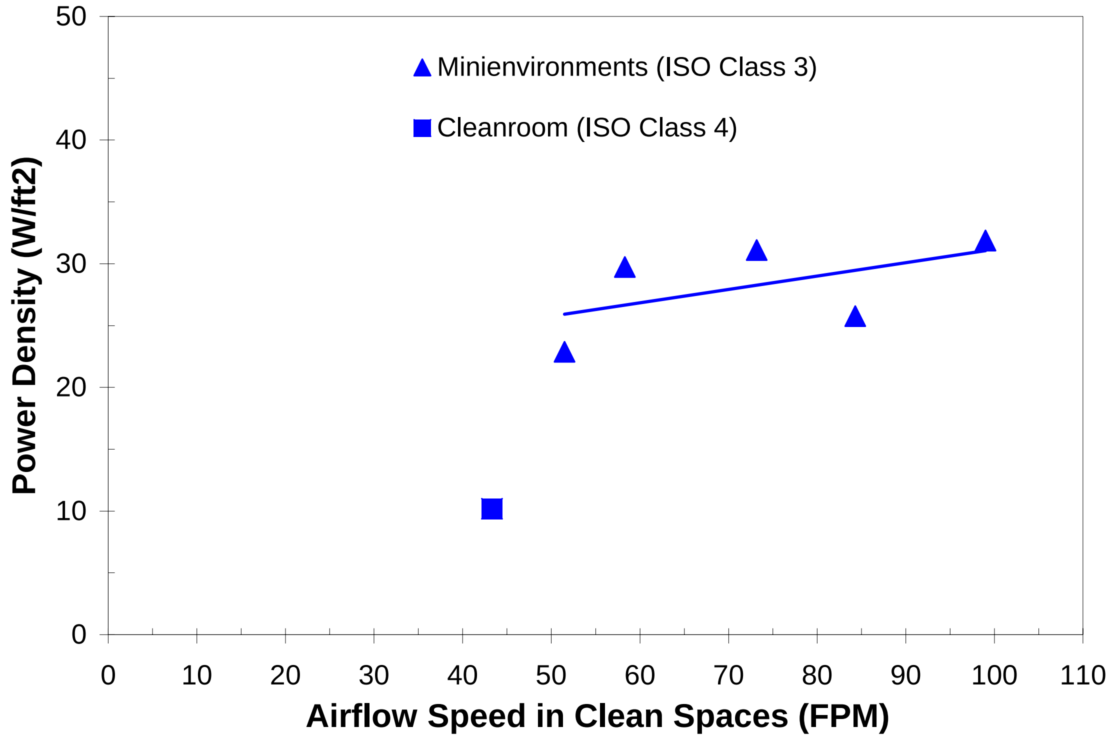

Figure 2. Power Density and Airflow Speeds for Various Minienvironments inside a Cleanroom

Related Best Practices

- Air change rate
- Fan-filter units
- Demand Control Filtration
- Fan Efficiency
- Right Sizing
- Filters

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