An examination of ACRs: An opportunity to reduce energy and construction costs

Now that cost-cutting has become paramount, it's time to discuss putting the growing list of energy-saving recommendations into practice

By Peter Rumsey PE, CEM

There are several conflicting sets of recommendations on what is the best airflow for cleanrooms. Recent articles in Cleanrooms magazine have explored the different ways of measuring or describing air flows and have discussed the upcoming Institute of Environmental Sciences and Technology (IEST; Rolling Meadows, Ill.) recommended changes; however, few industry observers have examined actual practices and the foreseeable impact on construction and energy costs.[1,2]

A recent benchmarking project conducted by Pacific Gas and Electric Company (San Francisco) and Lawrence Berkeley National Laboratory (Berkeley, Calif.) that measured air change rates in several cleanrooms verified that there is no consistent design strategy for air change rate, even for cleanrooms of the same cleanliness classification. Air change rates per hour (ACRs) are crucial for cleanroom designers because they have a significant impact on fan sizing and energy use.

Using best-practice ACRs can result in clean-filtered air, lower construction costs and reduced energy costs—a win-win situation for cleanroom owners.

Current design recommendations

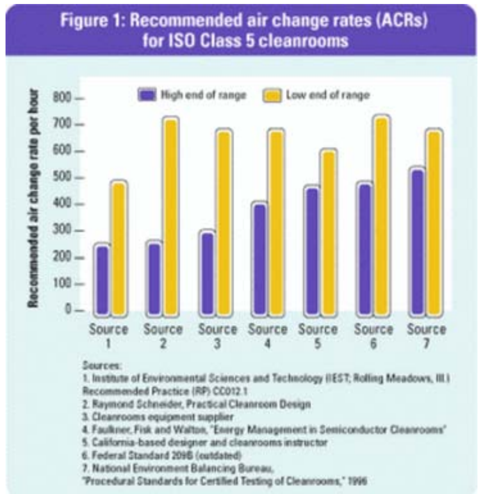
Today, designers and cleanroom operators have a variety of sources to choose from when looking for an ACR recommendation. There is no clear consensus on what is an optimum ACR, and many of the established guidelines are outdated.

A recent article in Cleanrooms magazine pointed out that many of the recommended ACRs are based on relatively low-efficiency filters that were prevalent 10 years ago.3 For example, today's widely-used 99.99 percent efficient filters are three times more effective at filtering out 0.3 micron particles than the 99.97 percent filters that were common 10 years ago. Ultra-low penetration air (ULPA) filters are even more efficient than those of a decade ago.

When Rumsey Engineers (Oakland, Calif.) conducted a review of recommended cleanroom ACRs, it found that there is no agreement on a correct rate. Most sources suggest a range of rates. These ranges tend to be wide and do not provide clear guidance to designers who need to use a set ACR value to specify fan sizes. Figure 1 shows the result of our comparative review of recommended ACRs.

Air changes affect energy and construction costs

ACRs are the single largest factor in cleanroom fan sizing, building configuration and energy costs. As shown in Figure 1, recommended rates can vary from 250 to more than 700 air changes per hour for an ISO Class 5 cleanroom.



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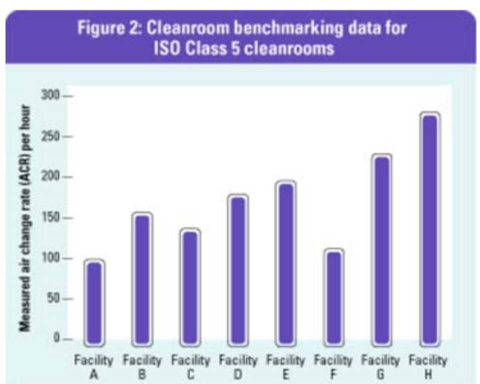
After gathering the results from its comparative review of recommended ACRs, Rumsey Engineers discovered that recommended rates for ISO Class 5 cleanrooms vary widely from source to source.

The high end of that range is almost three times the rate at the low end, yet the impact of this difference on fan sizing and motor horsepower is radically greater. According to the fan affinity laws, the power difference is close to the cube of the flow or air change rate difference. For example, a 50 percent reduction in flow will result in up to a factor of eight, or 87.5 percent reduction in fan power. Due to filter dynamics, the cube law does not apply exactly and, typically, the reduction is between a cube and a square relationship.

Even relatively conservative reductions of 10 percent to 20 percent in ACR provide significant benefits. A 20 percent decrease in ACR will enable close to a 50 percent reduction in fan size, with reduction calculation: 1 - 80%3. The energy savings opportunities are comparable to the potential fan size reductions.

While energy costs are not high on the priority list during the design and construction of cleanrooms, capital costs or construction costs are always important. Not so long ago, electronics, pharmaceutical and biotechnology companies did not need to worry much about construction costs. Currently, however, any designer would be irresponsible if construction costs or energy costs were ignored.



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According to the results of the Pacific Gas and Electric Company and Lawrence Berkeley National Laboratory benchmarking data, cleanroom operators can use ACRs that are lower than what is recommended practice for ISO Class 5 facilities.

It's a common assumption that making a cleanroom more efficient will drive up construction costs, which is often impossible in today's tight-fisted climate. However, well-planned ACR reductions can reduce both construction and energy costs. This is that elusive goal, a true win-win situation, which decreases the amount of work the mechanical system has to perform and offers high leverage for downsizing equipment.

Current practice

Pacific Gas and Electric Company and Lawrence Berkeley National Laboratory recently conducted a cleanroom energy benchmarking study.4 A variety of systems and practices were measured, including air change rates in eight ISO Class 5 cleanrooms. The results were surprising.

While the recommended design ranges for ACRs are from 250 to 700 air changes per hour, the actual operating ACRs ranged from 90 to 250 (see Figure 2). All of these cleanrooms were certified and performing at ISO Class 5 conditions. This shows that cleanroom operators can use ACRs that are far lower than what is recommended practice without compromising either production or cleanliness requirements.

This is often done to lower energy costs. However, these facilities did not take advantage of the fan sizing reduction opportunities during construction. As a result, most of the fan systems were operating at very low variable speed drive speeds.

What others have found

Air cleanliness is a critical component of any cleanroom, far outweighing energy saving priorities. Designers and operators need evidence from others who have tried similar strategies in order to address the perceived risks of lowering air change rates.

Fortunately, a growing body of data, case studies and research are available that document success. In a recent study by International Sematech (Austin, Texas), no noticeable increase of particle generation was found when air change rates were lowered by 20 percent in ISO Class 4 cleanrooms.5 A recent study at the Massachusetts Institute of Technology (MIT; Cambridge, Mass.) found that in a raised-floor-type cleanroom "with a small decrease in air velocity, such facilities will decrease particle deposition and maintain air unidirectionality."6

Other successes have been noted by cleanroom operators at Intel (Santa Clara, Calif.) and Sandia National Laboratories (Albuquerque, N.M.). Michael Dever, Intel's Oregon site utility manager, reported that an Intel project aiming to reduce both air change rates and ceiling HEPA velocities succeeded in achieving a 20 percent fan energy savings goal at a low cost of implementation. Sandia National Laboratories has also successfully reduced air change rates in their state-of-the-art ISO Class 4 and 5 cleanrooms. This is especially significant because Sandia pioneered laminar flow cleanrooms in the early 1960s.

Conclusions and recommendations

There is no doubt that more clarification and justification of optimal and safe air change rates are required. From the Pacific Gas and Electric Company and Lawrence Berkeley National Laboratory benchmarking data, it is clear that air change rates can be lower than what is currently recommended by several sources.

The benchmarking data suggests that an ISO Class 5 facility should be designed with an air change rate of around 200 air changes per hour. A conservative upper limit should be about 300, significantly lower than the high range of 700 indicated by some sources.

Facility designers and operators tend to err on the side of conservatism in their efforts to provide high reliability cleanroom support. More independent research on optimized air change rates based on contemporary filter efficiencies needs to be conducted to reduce the perceived risks of modifying standard practices.

Biotechnology and pharmaceutical cleanrooms are currently designed to meet current good manufacturing practices (cGMPs) that require high air change rates. These ACRs should be re-examined as part of upcoming revisions to the cGMP. In addition, IEST recommended practices updates should include lower ACR guidelines.

Using better air change rate practices will allow designers to offer lower construction costs as well as reduced energy costs while maintaining the high level of air cleanliness that is required in cleanroom facilities.III

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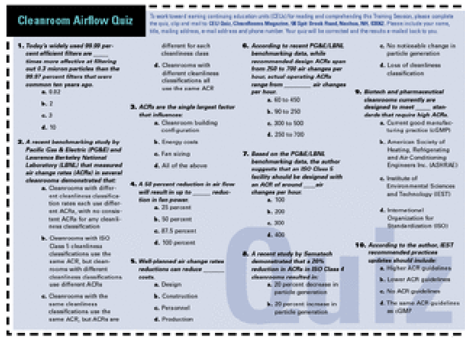
Cleanroom Airflow Quiz

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1. *Today's widely used 99.99 percent efficient filters are ____ times more effective at filtering out 0.3 micron particles than the 99.97 percent filters that were common ten years ago.*
   - a. 0.02
   - b. 2
   - c. 3
   - d. 10
2. *A recent benchmarking study by Pacific Gas & Electric (PG&E) and Lawrence Berkeley National Laboratory (LBNL) that measured air change rates (ACRs) in several cleanrooms demonstrated that:*
   - a. Cleanrooms with different cleanliness classification rates each use different ACRs, with no consistent ACRs for any cleanliness classification
   - b. Cleanrooms with ISO Class 5 cleanliness classifications use the same ACR, but cleanrooms with different cleanliness classifications use different ACRs
   - c. Cleanrooms with the same cleanliness classifications use the same ACR, but ACRs are different for each cleanliness class
   - d. Cleanrooms with different cleanliness classifications all use the same ACR
3. *ACRs are the single largest factor that influences:*
   - a. Cleanroom building configuration
   - b. Energy costs
   - c. Fan sizing
   - d. All of the above
4. *A 50 percent reduction in air flow will result in up to ____ reduction in fan power.*
   - a. 25 percent
   - b. 50 percent
   - c. 87.5 percent
   - d. 100 percent
5. *Well-planned air change rates reductions can reduce ____ costs.*
   - a. Design
   - b. Construction
   - c. Personnel
   - d. Production
6. *According to recent PG&E/LBNL benchmarking data, while recommended design ACRs span from 250 to 700 air changes per hour, actual operating ACRs range from ________ air changes per hour.*
   - a. 60 to 450
   - b. 90 to 250
   - c. 300 to 500
   - d. 250 to 700
7. *Based on the PG&E/LBNL benchmarking data, the author suggests that an ISO Class 5 facility should be designed with an ACR of around ___ air changes per hour.*
   - a. 100
   - b. 200
   - c. 300
   - d. 400
8. *A recent study by Sematech demonstrated that a 20% reduction in ACRs in ISO Class 4 cleanrooms resulted in:*
   - a. 20 percent decrease in particle generation
   - b. 20 percent increase in particle generation
   - c. No noticeable change in particle generation
   - d. Loss of cleanliness classification
9. *Biotech and pharmaceutical cleanrooms currently are designed to meet ____ standards that require high ACRs.*
   - a. Current good manufacturing practice (cGMP)
   - b. American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE)
   - c. Institute of Environmental Sciences and Technology (IEST)
   - d. International Organization for Standardization (ISO)
10. *According to the author, IEST recommended practices updates should include:*
    - a. Higher ACR guidelines
    - b. Lower ACR guidelines
    - c. No ACR guidelines
    - d. The same ACR guidelines as cGMP

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