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DEMAND-BASED VENTILATION IN CLEANROOMS: CONTROLLING AIRFLOW BY OCCUPANCY

Most cleanrooms run at full airflow around the clock, although the contamination load changes with the number of people in the room. Particle measurement is too slow and unstable to control airflow in real time. Proactive control, a principle patented by Halton, adjusts airflow according to the source of the contamination instead: the people present and the state of the process.

Why do cleanrooms use so much energy?

HVAC, and fan energy in particular, accounts for 50-80% of the total energy use of a cleanroom. For an operator with energy and emission targets, airflow is the first place to look.

Airflow rates are still commonly taken from tables, such as the 40-60 air changes per hour often quoted for an ISO 7 room, and the room runs at that rate regardless of what happens in it. These are rules of thumb that do not describe the contamination load of a specific room. The air change rate should be the result of the design, not its starting point.

What do the standards say about reducing airflow?

ISO 14644-16, the standard on energy efficiency in cleanrooms, advises against over-dimensioning and recommends basing the design on process requirements, contaminant source data and variation in use.

EU GMP Annex 1 requires the "at rest" particle limits to be reached after a clean-up period once operations have ended, with a guidance value of less than 20 minutes, determined during qualification. The guideline thus recognises that a room has different states and demands that performance in each is defined and verified.

Where does the contamination come from?

In many cleanrooms, people are the largest source of particles and of microbe-carrying particles. The emission depends on the number of people, their gowning and their activity, and process equipment adds a load that varies with the state of the process.

Source strength can be measured. EN 13795-2, written for surgical clean air suits, describes a dispersal chamber method for a gowned person. Halton measures the source strength of people and process equipment in its own laboratory or on site in the customer's facility, under real operating conditions. With that data, the airflow can be calculated for each load situation instead of only for the worst case.

Why not control airflow by particle count?

Measuring the particle concentration and letting the control system adjust the airflow is the obvious idea, but in a cleanroom it works poorly, for two reasons.

The first is the signal. In a test with step changes of concentration in a 170 m³ cleanroom chamber at 30 air changes per hour, the recorded concentration varied widely both during the changes and in steady state. A reliable reading requires averaging over several samples.

The second is speed. In a highly ventilated room the concentration changes within minutes when people enter or start working. A control loop that needs minutes to confirm a change is always behind, and the safety margin it needs to stay compliant removes much of the saving. Microbial contamination, which can be the factor that determines the airflow in pharmaceutical rooms, is not available as a real-time control signal with conventional culture-based methods.

How does proactive control work?

Proactive control reacts to the cause instead of the consequence. The system knows the source strength of the people and processes in the room and detects the changes that alter the load: how many people are present and what state the process is in. Airflow is set to match the load at the moment it changes, so the concentration stays stable rather than rising first and being corrected afterwards. When people leave, the airflow is kept at a purge level until the room has reached its at-rest state, so the clean-up time is met as part of the control sequence.

The principle applies to rooms with non-unidirectional airflow, where contamination is controlled by dilution. Unidirectional zones such as Grade A are governed by air velocity and are not part of it.

Halton has patented this principle and applied it in operating rooms, where staff are counted automatically during surgery and the airflow is adjusted accordingly. In cleanrooms occupancy varies even more: a room may be fully staffed for part of a shift and empty for the rest of the day.

How much energy can be saved?

Halton has simulated the principle for a 90 m³ Grade B cleanroom (ISO 7 in operation) over an eight-hour period with two to four people present. The airflow was dimensioned from source strength, with a 20% safety margin to the concentration limit.

With proactive control the maximum airflow needed was 0.5 m³/s, or 20 air changes per hour. Control based on particle measurement needed 0.9 m³/s, or 36 air changes per hour, and the airflow swung continuously between minimum and maximum because of the slow response. A rule-of-thumb design would run the same room at 40-60 air changes per hour all the time.

These are simulation results, and the saving in a real facility depends on its occupancy, gowning and process. Fan power falls steeply as airflow is reduced, and the cooling load falls with it.

What does it require in practice?

Proactive control is a system property and has to be designed in. Occupancy detection must be reliable, because it is now part of the contamination control. Air distribution has to remain effective at reduced flow as well as at full flow, and pressure differentials between rooms must hold in every operating mode and during the transitions.

Each operating mode also has to be qualified. In a GMP facility this means showing that cleanliness class and pressure differentials are met in every mode and that the clean-up time is achieved, and documenting the control logic in the contamination control strategy. Classification and qualification remain the responsibility of the facility owner.

In an existing cleanroom, monitoring data and Halton's on-site source strength measurements show how the load varies and how much margin the present airflow carries, so the savings potential can be estimated before any changes are made.

Summary

ISO 14644-16 calls for airflow based on actual sources and their variation instead of table values. Particle measurement is too slow to drive airflow, but occupancy and process state are known the moment they change. Halton's proactive control uses that information to give the room the airflow it needs at each moment.

If your cleanroom has varying occupancy and energy targets to meet, get in touch with Halton to find out what proactive control could save in your facility.