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## Ten tips for cleanroom energy efficiency

*Significant energy savings potential exists in most cleanroom facilities in heating, ventilation and air conditioning (HVAC), process cooling, compressed air, and other utilities.*

By Peter Rumsey, P.E., CEM; Lee Eng Lock & Chris Lotspeich

HVAC systems consume up to 50 percent of a microchip fab's electricity. Much of this wasted energy and excess capacity results from minimizing first cost instead of cost-of-ownership in fast-track design and construction. High-efficiency design and equipment can cost more up front. Penny-wise, pound-foolish shortcuts and cost-cutting degrade performance and increase energy bills for a facility's lifetime.

Improvements are blocked by nonsensical financial hurdles. Upgrades are commonly held to higher return on investment (ROI) standards than are purchases of new equipment. Most facilities cap retrofit payback periods at two years or less—effectively, a 50 percent ROI at least, compared to 10 to 15 percent ROI (or up to a seven-year payback) requirements for new capital assets. These standard practices undermine competitiveness and shareholder interests. In today's mature industry, innovation has to happen in facilities as well as in product design.

The business case for energy efficiency is strong. Mining this waste adds profit at less risk than selling

product, for every dollar of saved overhead goes to the bottom line. Energy accounts for less than two percent of a chip's cost, yet electricity can be a chipmaker's largest single operating expense, totaling millions of dollars annually at a single fab. In new plants, energy-saving measures can save capital and construction time. Initial design offers the biggest bang for the buck, but economical retrofit opportunities abound. Retrofits usually offer payback periods of less than two years when undertaken collectively, with faster ROI for some measures.

Here are 10 energy-efficiency tips for new and existing facilities, offering proven techniques with minimal risk, low or no cost, and attractive payback periods:

### 1. Low Face Velocity Design

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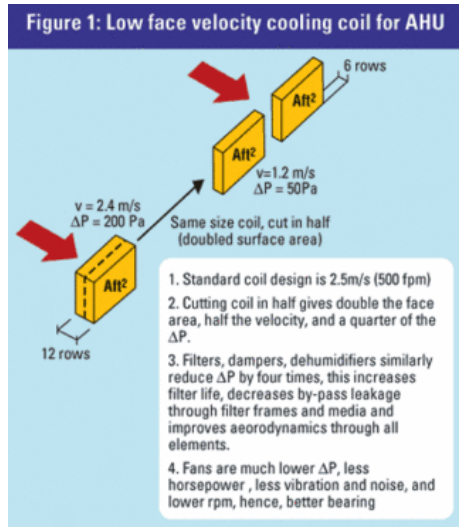
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Face velocity is the speed at which air passes over the filters or heating/cooling coils in an air-handler unit (see Figure 1). Most engineers size air handlers with a "rule of thumb" of 500 feet per minute (fpm). This saves time, but increases cost of ownership. Low face velocity (LFV) design uses larger air handlers with smaller fans to maintain flow at lower velocity, saving energy and lifecycle costs.



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*Low face velocity (LFV) design uses larger air handlers with smaller fans to maintain flow at lower velocity, saving energy and lifecycle costs.*

Pressure drop determines fan energy consumption. The "square law" says that pressure drop falls in proportion to the decrease in velocity squared. A 20 percent reduction in face velocity results in a 36 percent reduction in pressure drop; a 50 percent velocity decrease reduces pressure drop by three-fourths. The "cube law" says that the change in fan power is roughly the cube of the change in flow. A 50 percent reduction in flow reduces fan power by almost 88 percent.

Therefore, wider air handlers with larger filter and coil areas need much less fan energy, and can use smaller fans and motors. Smaller fans add less heat to the air, reducing cooling requirements. Shallow coils are easier to clean and work more effectively, so chilled water temperatures can be higher. Filters work better and last longer at lower face velocities.

LFV design reduces both air- and water-side pressure drop, eliminating water carryover from cooling coils. Streamlined layouts with few sharp angles can reduce pressure drop 10 to 15 percent.

LFV design can also lower pressure drop by a factor of four. Target at least 25 percent reduction in energy costs and variable speed drive (VSD) fan sizes. Optimal face velocities should be in the 250 to 450 FPM range, depending on the application and energy costs.

## 2. Air Change Rates

Cleanroom airflow rates are set to maintain cleanliness or particle count. Airflow can be assessed in terms of air change rates per hour, and this determines fan sizing, building configuration and energy costs. Rate reductions can lower construction and energy costs while maintaining cleanliness. A 20 percent decrease in air changes enables an almost 50 percent reduction in fan size. Air cleanliness is far more important than saving energy. Yet a growing body of research has documented successful reductions.<sup>1</sup>

There is no clear consensus on optimal air change rates. Many guidelines are outdated and based on older, relatively low-efficiency filters. Air change rates were surveyed at recommendations ranging from 250 to more than 700 for ISO Class 5 cleanrooms.

Pacific Gas and Electric and Lawrence Berkeley National Laboratory were assisted in benchmarking eight ISO Class 5 cleanrooms. That study revealed actual operating air change rates of 90 to 250—far lower than recommended practice, without compromising production or cleanliness. That suggests an ISO Class 5 facility design air change rate of around 200, with a conservative upper limit of 300.

## 3. Motor Efficiency

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Motors use most of the cleanroom facility electricity. Continuous-duty electric motors consume their capital cost value in electricity roughly every month. Modest efficiency and sizing improvements make most retrofits cost-effective. Raising efficiency by a few percentage points can be profitable.

Use premium-efficiency motors; they do not necessarily cost more. "High efficiency" is the legal minimum. Minimize the load before sizing the motor. VSDs enable efficient operation at varied output.

#### 4. Variable-Speed Drive Chillers

VSD chillers save substantially on energy and cost. Many cleanroom designers and operators believe VSD chillers are unnecessary because loads are constant, and multiple-chiller plants can be controlled to run at high loads. But chillers at constant load might operate below full capacity. VSD chillers save energy whenever loads are under 90 or 95 percent. A 1,000-ton chiller loaded constantly at 70 percent capacity would save \$20,000 to \$30,000 annually with a VSD, based on chiller manufacturer data and \$0.05/kWh, with a pay back of about one year.

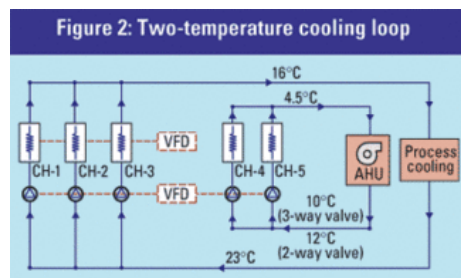
Multiple-chiller chilled water plants rarely run all at high loads. Typically, the site load does not neatly match the plant's increments of chiller capacity. Many operators run a redundant chiller for reliability; if one fails, the other chillers can immediately cover the entire load. Thus, chilled water plants often operate chillers at average loads of 60 to 80 percent.

It's cost-effective to specify VSDs whenever new chillers are purchased. They reduce energy costs while maintaining the reliability of running additional chillers. Much research and experience verifies VSD chiller effectiveness. After more than 20 years, VSD chiller manufacturers now make highly reliable units that should be used in all new and renovated cleanroom facilities.

#### 5. Dual Temperature Cooling Loops

Cooling systems are typically designed to serve peak load, regardless of how frequently that occurs. The chilled water temperature setpoint for the process cooling loop is often determined by the most extreme thermal requirements of a small subset of the total load, such as one or two tools out of many. This results in excess cooling capacity and inefficient operation at partial loads. Chillers operate at lower efficiencies when run at colder supply temperatures. On average, each Fahrenheit degree of increase in chilled water supply temperature improves chiller efficiency by more than one percent.

It's often much more efficient to isolate the loads and produce chilled water at two different temperatures (see Figure 2). Designers can use parallel piping loops to isolate those subsystems, with the greatest cooling needs from others that can operate at less demanding conditions. One medium-temperature loop (e.g., 55° to 65° F) with dedicated chillers optimized for that chilled water supply temperature can serve the majority of a fab's load. A second lower-temperature loop (e.g., 39° to 43° F) with a smaller high-efficiency chiller can serve the load's most demanding subset.



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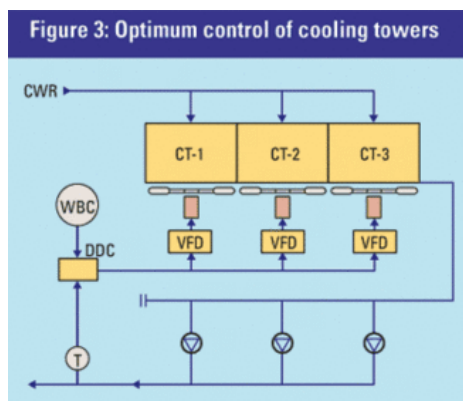
*Designers can use parallel piping loops to isolate subsystems, with the greatest cooling needs from others that can operate at less demanding conditions.*

This approach can improve overall chilled water plant efficiency dramatically—by 25 percent or more. Higher temperature chillers cost less than lower temperature chillers of equal capacity.

#### 6. Cooling Tower Optimization

High-efficiency towers improve chiller efficiency by lowering the condenser water supply temperature (see Figure 3, page 18). Typical cooling towers require about 100 watts of energy per ton of cooling output from the chillers. This can be improved by up to a factor of 10 with close approach temperatures, more efficient airflow designs, premium-efficiency fan motors with VSDs, reduced height to limit pumping lift, and increased fill area (oversizing the tower).

The approach is the difference between the outside air wetbulb temperature and the chilled water supply temperature, and should be controlled to between 3° and 5° F.



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*All cooling towers should operate in parallel to maximize evaporative cooling over an increased surface area.*

Many facilities with multiple towers use one- or two-speed fans and stage the towers in series. One is run at full speed until a marginal increase in load exceeds its capacity, then another tower is switched on at low or high power. This strategy results in large, incremental changes in capacity, frequent overshooting or undershooting of the required load, and a sawtooth-shaped energy use profile, representing a loss in chiller efficiency.

Instead, all towers should operate in parallel to maximize evaporative cooling over an increased surface area. Run more towers at lower speed. Use VSDs to modulate fan speed to closely follow the load and take advantage of cube law fan energy savings at slower speeds.

Facilities commonly dedicate one cooling tower to each chiller to supply condenser water. This configuration does not allow the chillers to take advantage of parallel tower operation. Add common headers to the condenser water system to allow parallel tower operation, regardless of the cooling demand.

## 7. Free Cooling

Economizer cooling—using outside air—is widely used in commercial buildings. Another "free cooling" strategy applies to facilities with constant chilled water requirements and fan coil systems, such as cleanrooms.

Free cooling creates chilled water directly from the cooling towers in low temperature or low humidity conditions, reducing or replacing the use of chillers. Depending on the climate, free cooling systems can reduce cooling system energy use by a factor of 10 (e.g., from 0.5 kW/refrigerative ton to 0.05 kW/ton).

Direct heat exchange to the process loads enables free cooling at warmer outside air temperatures over more hours than are possible with a secondary or tertiary system. The cooling water is isolated from the chilled water by a plate-and-frame heat exchanger with a close approach (e.g., 2° F). When the temperature and humidity are sufficiently low, the cooling towers can operate alone, and in cases without fans. Many regions experience large periods annually when free cooling is possible, as indicated by psychrometric charts.

## 8. Heat Recovery

Many facilities consume energy to create heat while spending more energy removing "waste" heat from their processes, without matching up these two activities. Recovered heat can be used for outside air preheat, supply air reheat, and other purposes. AHU preheating coils can use wastewater to preheat outside air (or precool it in hot climates).

Reheat coils can use waste heat from air compressors or chiller condenser return water,

saving both chiller energy and boiler fuel. Heat exchangers can allow energy transfer between media that should not mix or make direct contact.

## 9. Variable Pumping

Many engineers and managers resist using VSDs due to past equipment failures and increased control complexity. Reliability takes precedence over energy savings, and many older VSD models were unreliable. In the last decade, however, VSDs have increased in reliability and decreased in cost. Many critical systems are now run by VSDs.

We believe it is safe and cost-effective to use VSDs on many systems and all forms of pumping in cleanroom facilities. Indeed, it is arguably irresponsible to not use VSDs given their ROI, with payback periods under one year.

Chilled water and condenser water pumping systems benefit from variable flow. Chilled water and condenser water systems have minimum flow requirements, typically between 50 and 75 percent. Yet small reductions in flow reap significant cube law energy savings. A 20 percent flow reduction yields an almost 50 percent pumping power reduction.

Most existing chilled water systems use a constant-flow primary/variable-flow secondary pumping scheme, with VSDs on secondary pumps. With VSDs, all chilled water valves should be two-way type, or the benefit of variable pumping is lost.

In new facilities, variable primary-only pumping eliminates the need for secondary pumps and reduces construction costs. Properly implemented, this simple and reliable system saves large amounts of energy by varying chilled water flow through the chillers. This technique is widely publicized by chiller suppliers and professional associations, such as American Society of Heating, Refrigerating & Air Conditioning Engineers (ASHRAE).

## 10. Centrifugal Compressors

Air compressor improvements save large amounts of energy. Centrifugal compressors are oil-free and much more efficient than screw compressors, but they cannot unload, making them inefficient at partial loads. The most efficient and economical approach combines centrifugal and screw compressors. Size centrifugal units to match base loads, with smaller screw compressors for peaking loads. Compressors should have heat recovery systems.

Another strategy is to operate one large compressed air plant for the entire site with high-capacity centrifugal compressors plus large air receivers and piping to create a reservoir. This enables the plant to maintain a constant load, reducing loading and unloading that degrades efficiency and wears out the equipment.

## References

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