IMPROVING WAFER FAB RESOURCE REDUCTION USING A SYSTEMS SYNERGY APPROACH

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Biography

As IDC's Director of Technology, Mr. O'Halloran has developed many advanced concepts for semiconductor facilities. He is an invited speaker for conferences, SEMATECH, and has provided 300mm consultation to leading semiconductor manufacturers. He has developed a detailed breakdown of construction costs in a computer model for analyzing fab size, facility capital, and operating costs. He is a mechanical engineer with 25 years of experience in semiconductor facility design, including the design of cleanrooms and specialized systems. He is a SEMI member and former Chairman of SEMI's task force for the development of standards for semiconductor equipment and equipment installation specifications.

Abstract

The semiconductor industry has often approached the challenge of resource reduction by attempts to analyze and optimize a wafer fab's discrete operational elements one at a time. However, the inherent complexity and delicacy of the relationships among a fab's many operating systems suggests that such a simple approach is not sufficient to achieve the resource reduction benefits driven by the greater demands of today's microelectronics market. This paper presents a wafer fab resource reduction technique that focuses on the complex interrelationships of a fab's many systems, with the goal of achieving greater resource reduction success through a synergistic rather than discrete optimization strategy. This analysis approach encompasses a range of the complex systems typical in fabs, and reviews some stand alone, specific technologies that have proven useful for semiconductor facilities.

Data

Resource reduction technique — The basis of the technique is a multi-step process, the basic steps of which are the following:

1. A mass and/or energy balance drawing is developed to show the systems involved.
2. An interrelationship diagram is created.
3. A mass and/or energy balance model is created based the above.
4. Sensitivity analysis is performed using the model to determine the drivers of the resource usage.
5. Results of the sensitivity analysis are studied to determine the potential for resource reduction.
6. The opportunities for resource reduction are prioritized based on their individual and synergistic cost benefit potential.

The following is a simplified example of the process.

The example is based on the design day electrical energy usage of a semiconductor "fab" clean-room. To keep the example simple, several sub-loops and all secondary supporting operations have been eliminated. Figure 1 shows a first order energy balance diagram for the cleanroom.

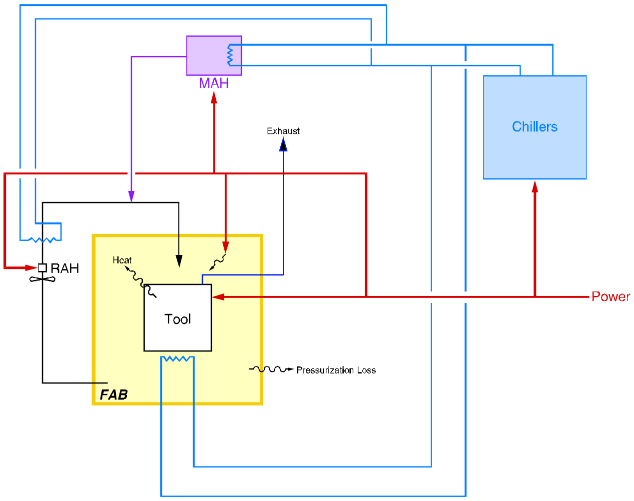

Figure 1. *Cleanroom First Order Energy Balance*

Figure 2 shows the interrelationship of the elements in the energy balance.

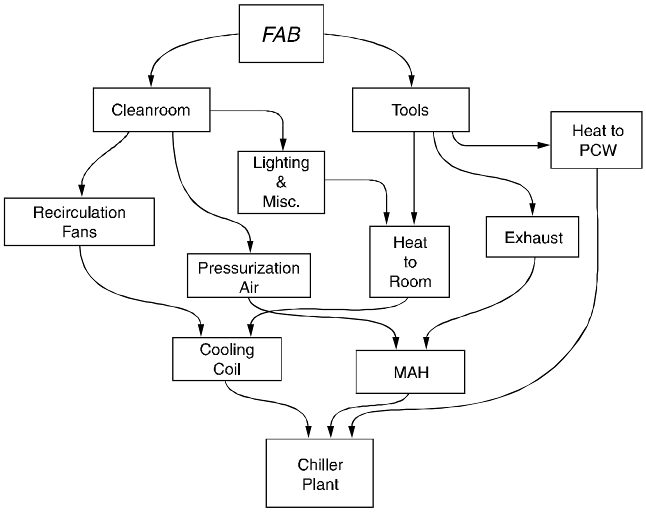

Figure 2. *Fab Energy Balance Inter-relationships*

These two figures were used to create a mathematical model of the process. As an example of the mathematical model development, consider the power consumption of the chiller plant. The chiller plant uses electrical power to transfer energy from the process cooling water systems and chilled water systems to ambient air. Typical chiller efficiency is on the order of 0.6 kW/ton of cooling. However, this efficiency is actually a function of the temperature of the chilled water system (among other things) as shown in Figure 3.

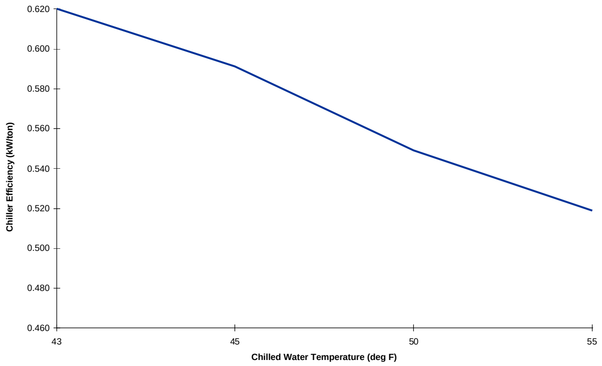

Figure 3. *Influence of Temperature on Chilled Water System Efficiency*

A study of the interrelationship diagram shows the driver for this temperature to be the temperature and humidity operating conditions in the fab, and the approach temperature of the cooling coil in the makeup air handler.

A similar analysis of other variables produces a mathematical model using the variables and outputs shown in Figure 4.

Tool Power	
Tool Power	50 watts/sf
Recirculation Fan Energy	
Recirculation Fan Energy	0.00035 kw/cfm
Recirculation Air Volume	75 cfm/sf
MUA Fan Energy	
MUA Fan Energy	0.0015 kw/cfm
Exhaust Loss	4 cfm/sf
Cleanroom Pressurization Loss	0.5 cfm/sf
Design Conditions	
Outside Air Temperature	89 Deg. F dry bulb
Outside Air Wet Bulb	72 Deg. F wet bulb
Fab Design Dry Bulb	70 Deg. F dry bulb
Fab Design Relative Humidity	42% Relative Humidity
Design Parameters	
MUA Coil Approach Delta Temp.	8 Deg. F
Cooling Tower Approach Temp.	10 Deg. F
Power Usage	
Tool Power	0.05 kw/sf
Recirculation Fan Energy	0.02625 kw/sf
MUA Fan Power	0.00675 kw/sf
Chiller Power	
Tool Power	0.007425 kw/sf
Recirculation Fan Energy	0.003839 kw/sf
MUA Fan Power	0 kw/sf
MUA Cooling Load	0.015307 kw/sf
Subtotal	0.026631
Total Power	**0.109631 kw/sf**

Figure 4. *Variables Influencing Fab Energy Consumption*

A sensitivity analysis was done on the model, using total power per square foot as the target output and a +/- 10% change in all driver variables. The result of this analysis produced the tornado graph shown in Figure 5.

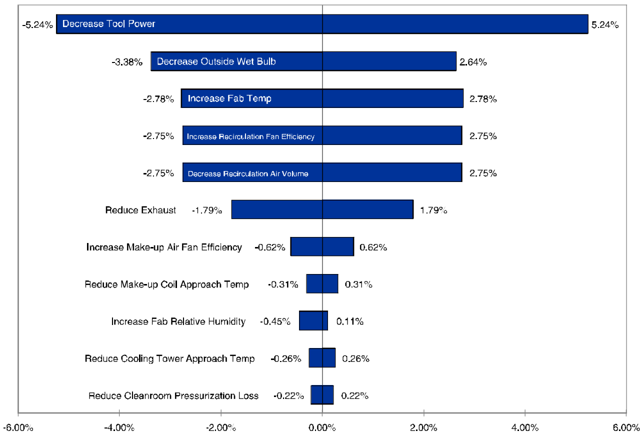

Figure 5. *Analysis of Energy Consumption Ranges of Variation*

Next, each element of the tornado graph is assessed for its ability to change. Figure 6 shows an example outcome of such an effort.

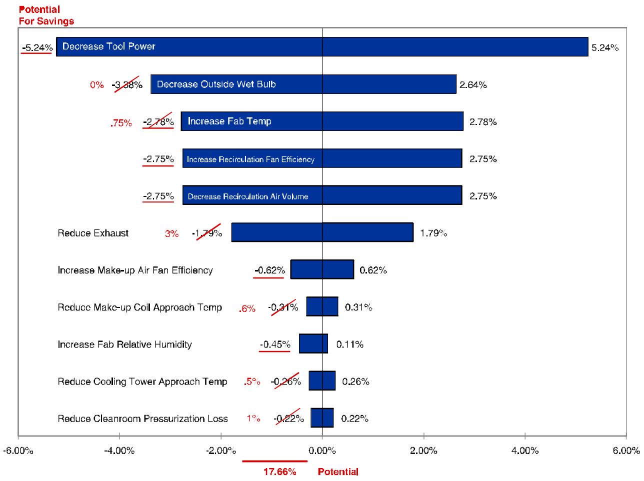

Figure 6. *Assessment of Potential for Energy Consumption Reductions*

Finally, a cost benefit analysis (not included in this paper) could be done to determine individual and synergistic impacts of changes to the variables and to investigate new design alternatives.

The above is an abbreviated example used for the purpose of illustrating a process that is in practice an intensely analytical series of steps that are repeated over and over as mathematical models are applied, modified, and refined to hone a comprehensive range of solutions capable of optimizing an entire fab operation, not just a portion of its components.

Example technologies — The following is a review of some of the specific technologies that have been successfully implemented to achieve energy savings and resource reductions in microelectronics manufacturing facilities. None of these technologies is still merely theoretical; all have been field-applied and proven.

Power — Power reduction strategies yield revenue benefits through the obvious form of utility dollars saved, and also through energy reduction rebates that are widely available to industrial users from utility providers around the world. In addition, reduction in chiller plant power consumption and operating cost can sometimes also be credited. The following are some key areas of opportunity for such savings.

- Premium efficiency motors. These are often overlooked during a project's procurement process because they are more costly than conventional motors. When viewed in terms of long-term cost-saving potential, however, premium efficiency motors often involve short payback periods and generate impressive residual returns on investment of the life of a facility. When owners are given the opportunity to review the value of these motors in specifically documentable form, they are more inclined to call for the use of premium efficiency motors in applicable equipment throughout a facility.

- Adjustable frequency drives (also known as variable speed drives, or VFDs) on motors and pumps. To maximize efficiency and reduce energy consumption throughout a facility, adjustable frequency drives can be incorporated into many motors and pumps used for air and fluid handling equipment, and any other systems subjected to varying loads, including cooling towers. In addition to realizing energy savings throughout the facility, this design approach also offers greater control flexibility to facility operators.

- High-efficiency chillers. These are often overlooked by fab designers, who may specify commercial grade chillers instead of the high-efficiency industrial grade equipment that is better suited to the achievement of long-term energy savings. Care must be taken in the specification of high-efficiency chillers, however. Engineers must study the shape of a facility's anticipated climate load so that the larger chillers are configured to remain loaded and thereby able to consistently operate at their highest efficiency levels.

- Heat recovery from condensor water. A specialized design approach has been devised that enables an industrial facility to derive approximately 40 percent of its heating needs through heat recovered from condensor water using heat exchangers. This approach has been successfully implemented in multiple semiconductor wafer fabs.

- Acoustically designed fans. This innovation is the result of a collaboration between a design firm and an equipment manufacturer to apply acoustic technology used in jet engine design to the design of extremely high-performance cleanroom fan systems. The fans minimize noise production and thus avoid a need for the space, equipment cost and energy costs associated with noise attenuation systems, while saving additional energy through higher efficiency performance. This technology has been successfully implemented in three recent semiconductor wafer fabs.

- Condensor water temperature reset. A reduction in the set point for condensor water improves chiller efficiency as the condensor water supply sent to the chillers declines. This strategy must be carefully implemented, however, since it carries a point of diminishing return. A common oversight is to apply this strategy to excess by setting the condensor water temperature too low. This can actually result in higher energy costs incurred by over-performing chillers. There is an optimal set point for condensor water temperatures that needs to be determined through careful analysis of the relationship between chiller capacities and the specific production requirements of a given facility.

- Strategic building insulation placement. Rather than universally applying insulation specifications for a wafer fab based on local codes, building designers should strategically adjust the use of insulation based on internal as well as external factors. Often insulation requirements are formed primarily in response to climatic conditions outside an entire facility, rather than in response to the activities being conducted within individual zones within the building. When inside activities are more actively factored in as part of an overall energy reduction strategy, external ambient temperatures often become secondary to the consideration of heat loads being generated within respective internal zones. The result of a zone-by-zone analysis may range from specification of more insulation in areas of low activity to the elimination of insulation completely in high-activity zones to facilitate heat offloading.

- Reduce process exhaust. Every unit of process exhaust that can be eliminated has a compound impact on makeup air handlers, chillers and abatement systems, including waste treatment of spent abatement chemicals. It is important for facility owners and designers to work closely with tool manufacturers to modify their recommended exhaust rates. Those recommended rates may be needlessly conservative. Owners also should feel entitled to demand that tool manufacturers minimize the process exhaust requirements at the tool, and they should review the tool manufacturers' recommendations for cleaning.

- Reduce general exhaust. This also has a compound impact on makeup air handlers and chillers. One way to reduce general exhaust is to minimize H occupancy areas where codes require constant exhaust rates of one cfm per square foot. Per UFC 8003.1.8.2, non-continuoius exhaust systems are allowable on approval of local fire departments. Another approach to consider is to have code-required exhaust controlled by occupancy sensors or chemical sensors. Sometimes areas adjacent to H occupancy areas are also designed as H occupancy areas to eliminate the need for fire dampers. While this lowers initial costs, it always creates a higher overall life cycle cost.

- Natural or passive ventilation. This is allowed by code for hazardous material storage areas unless they are H6 HPM storage areas, in which case mechanical ventilation is required. Mechanical ventilation may not have to be continuous.

- High-frequency electronic ballast lighting. While use of this technology is not typical in cleanrooms, we apply it in cleanrooms as well as throughout a facility to enable owners to benefit from the considerable reduction in energy usage that the technology provides, and the accompanying cost savings. High-frequency electronic ballast lighting allows achievement of the highest output with the lowest energy consumption by delivering power in high-frequency pulsations rather than a steady flow. Typically, high-frequency electronic ballast lighting consumes 10 percent less energy than conventional magnetic ballast approaches, and offers the additional benefit of substantially cooler operation. Those savings multiply to very considerable levels over the full duration of a facility's operational life cycle. This technology contributes the additional benefit of reducing cooling loads throughout the facility.

- Zonal sensors to limit energy waste. Occupancy sensors and independent programmable zonal controls allow facility operators to individually program local areas for lighting, heating and air handling based on anticipated occupancy needs. This strategy responds to the fact that occupancy levels vary considerably among the various types of spaces throughout the facility according to intended use of the space, day of week, time of day, etc. The various forms of controls used to implement this technique include motion detecting occupancy sensors, zonal photo cell controls that automatically reduce lighting levels in accordance with ambient light, programmable timers, and multi-level dimming switches that allow adjustment of lighting levels within a range, depending on the varying needs of space users. To save additional costs, a multi-level dimming capability can be designed into the facility's regular lighting ballasts and circuitry rather than through more expensive specialized dimming systems. The capability to individually program areas for lighting, heat and air handling allows operators to effectively implement energy conservation measures on an ongoing basis that can be customized for each individual space and its respective type of usage.

- Metal Halide (HID) fixtures. These offer superior performance and energy efficiency over conventional flourescent fixctures. HID lighting yields considerably more lumens per watt than flourescent fixtures, allowing them to achieve superior intensity while allowing fewer fixtures in the cleanroom, producing additional energy savings.

- Use of T5 vs. T8 or T12 fixtures, which consume fewer watts per lamp.

- Use of daylighting. In office and asembly areas, strategic daylighting can greatly reduce electrical lighting loads while saving additional energy through reduced cooling requirements. The added costs of photocell driven dimmers, lightshelves and higher ceilings can be substantially offset by the savings produced through reduced HVAC tonnage, ductwork, and overall operating costs.

- Integrated photovoltaics for standby power. The current cost associated with this approach is approximately five dollars per installed watt, not including batteries. This may not be much of a premium over the cost of diesel generators when it is considered that the generator requires an enclosure, ventilation, a fuel tank and a loading station. Photovoltaics also eliminates the need for such other cost issues as monthly diesel tests and fuel use, and eliminates a potential source of pollution that can contribute to cleanroom contamination and site noise. Curtainwall systems are now available which support PV panels integral to a building's skin, as well as skylight systems for semi-transparent PV panels which allow light penetration and solar electricity generation.

Water — The recent advent of water-intensive processes such as chemical mechanical polishing (CMP) has put additional pressure on manufacturers to increase conservation efficiency. New recycle/reclaim strategies are evolving making these savings possible, some of which are reviewed below.

- Water reclaim systems. Process wastewater can be collected for onsite treatment prior to discharge into the municipal treatment system, and used ultrapure water can be recycled into the industrial wastewater system. This approach can offer the capacity to recycle a large percentage of a facility's ultrapure water.

- Application of discharged wastewater for agricultural irrigation. This innovative use of reclaimed water allows irrigation discharge to serve multiple purposes, including irrigation of on-site landscaping, and irrigation of local agricultural crops via special routing of discharged water to off-site users. This approach has been applied to work in reverse as well- providing for irrigation of campus landscaping by using water reclaimed from nearby effluent treatment plants.

- Sulphuric acid recycling. Another unusual approach is the collection and re-use of sulphuric acid for wastewater neutralization and pH control at a fab's cooling towers. Typically, facilities of this kind have to purchase and introduce new supplies of sulphuric acid for this purpose, so this approach offers the benefit of cost saving as well as environmental responsibility. On one recent project, this approach had an estimated payback period of under two years.

- Deionized water reject recovery. Design approaches have been devised that enable the recovery of millions of gallons of DI reject water per year by recycling to scrubbers. On one recent project, this approach had an estimated payback period of three years.

- Resource-reducing landscaping. The landscape plan for a site is the starting point for facilitating the viability of low-water (xeris) landscaping for large-scale industrial developments in water-scarce areas. An entire landscape palette can be selected based on low water consumption and suitability for irrigation by reclaimed water from nearby effluent treatment plants when feasible. Such environmentally responsbible landscapes feature little or no turf, instead relying on indigenous, low-maintenance plant materials that require little fertilization, pesticides or irrigation. While many developments in arid areas continue to rely on water-intensive landscaping, progressive facility planners can produce a landscaping scheme that is aesthetically pleasing while environmentally responsible, respectful of native plant material, and able to produce cost savings in arid areas where water may carry a premium price.

Equipment — In earlier times, equipment innovations were responsibility of equipment manufacturers. Today, progressive design firms take the initiative to collaborate with equipment manufacturers to engineer equipment improvements that bring long-term value to facility owners and contribute to a facility's overall energy reduction approach. Two examples of such collaborative innovations are reviewed below.

- Optimized makeup air handler. Industrial design firm IDC and York/Miller-Picking Subsidiaries, a large mechanical equipment manufacturer, combined forces to design an advanced air handler called OptiMAH that provides higher energy efficiency, lower overall life cycle cost, and easy assembly in the factory. In conventional makeup air handlers, heat removed during the dehumidification process is wasted, and new energy is used for reheating. The optimized air handler recovers heat from dehumidification and recycles it so that no new energy is needed for reheating. This product produces the greatest energy savings in warm, humid climates. Benefits include lower chiller and boiler plant operating costs; reduced chiller plant capacity requirements and capital costs; and reduced or eliminated heating plant capacity requirements and capital costs. In one application in Singapore, the use of these air handlers allowed reduction of capital costs related to chillers by $1 million; allowed the deletion of a boiler plant saving $250,000; reduced energy costs by $1.3 million per year; and produced a simple payback period of under two months.

- Optimized recirculation fan tower. This product is also the result of a collaboration between design firm IDC and AcousitiFLO, a major design/build mechanical contractor, both of which specialize in service to high-technology industries. The product's development was inspired by the realization that technology used to control air flow and fan noise for industrial applications had evolved little since 1940. The optimized recirculation fan tower design uses finite element fluidflow analysis and advanced computer models to produce unprecedented control over cleanroom airflows, minimizing both power consumption and noise generation. Sample savings produced by this air handling system are shown in Figure 4.

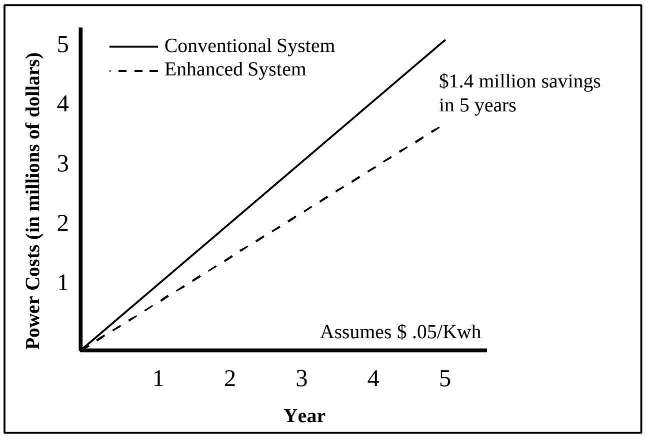

Figure 4. *Potential Power Savings in 7.7 Million CFM Cleanroom Using the AcoustiFLO Optimized Recirculation Fan Tower*

Conclusion

There is often a temptation to believe that if single systems within a fab are optimized, the sum of such efforts will be universal improvement throughout the fab. Unfortunately, this idealistic outcome is far from the reality. A conclusion based on extensive experience with the design, construction and operation of semiconductor wafer fabs is that resource and energy reductions can be most effectively achieved when they are implemented not through the optimization of one system at a time, but rather through a comprehensive strategic analysis and thorough understanding of the complex interrelationships among the many systems that comprise a fab. This approach does not apply only to the design of new fabs, however; significant energy- and resource-reduction benefits can also result for existing fab operations, provided they too are addressed through a broad and integrated strategic approach rather than a system-by-system optmization.

Acknowledgments

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