Energy Management Optimization
with
Computerized Refrigeration Control

Recent advances in refrigeration control systems have allowed a shift from deriving energy savings solely from control efficiencies gained at the individual equipment level to taking a plant-wide design perspective. It is now feasible *and* cost-effective to consider all sources of energy usage and flow throughout a facility when designing a refrigeration control system with the objective to maximize total plant energy savings.

The history of microprocessor control technology as applied to the refrigeration industry can be thought to have occurred in three phases. First appearing in the 1980s, the substantial achievement of these early efforts was effectively the substitution of solid state electronics for the relay switching functionality of the electro-mechanical devices being replaced. The main benefit of this was greater control precision.

The next generation of computer controls that began rolling out in the 1990s began to focus on refrigeration energy efficiency, primarily at the individual equipment level. During this time, control systems began capturing energy efficiencies from improved system compressor capacity control, cycling off satisfied evaporator fans, floating down condenser and up suction pressures when possible, and reducing defrost frequency via a number of techniques. Also, controls in this decade began offered variable frequency drive (VFD) motor control on compressors, condenser and evaporator fans.

Computerized refrigeration control technology in the new Millennium delivers even higher energy efficiencies by employing a comprehensive, whole-system approach to refrigeration equipment operation. These greater efficiencies are made possible with sophistication control algorithms that continuously monitor and analyze operating conditions and energy consumption on a plant-wide basis using a refrigeration “Supply / Demand” perspective.

Two examples of this whole-system, comprehensive approach are strategies for Load Management and Coordinated Evaporator Operation.

Refrigeration Load Management

Refrigeration plants have energy savings potential made possible by considering any refrigerated load that is within desired operating parameters, and consequently eligible for temporary shut-down, as an energy resource. Other non-refrigerated plant loads, such as lighting, battery chargers and HVAC systems, can also be considered energy resources from their temporary shut down. Additional energy savings may be acquired from the coordinated operation of load-producing evaporators in a common refrigerated zone.

Refrigeration loads, typically evaporators, create refrigeration *demand* which is met by compressor and condenser operation rejecting heat into the atmosphere. By managing load or demand “at the source,” it is possible to effectively manage the entire refrigeration system. That is because as the refrigeration load (*Demand*) declines, compressor and condenser (*Supply*) power requirements are deduced. And then as the refrigeration system stabilizes, compressors and condensers benefit from opportunities for tighter control and improved efficiency.

The following describes specific refrigeration load management strategies made possible by the most current controls hardware and software technology available. These strategies reduce total plant energy use through coordinated control of refrigeration equipment associated with load.

Coordinated Evaporator Temperature Control

Conventional Random Evaporator Cooling Control

The conventional approach to evaporator control utilizes independently operating thermostat-type functionality. This results in random total refrigeration load variations under all but full load conditions. For example, during moderate load conditions, an individual evaporator air unit may be off or on roughly 50 percent of the time. A conventional control system may, at any point in time, have nearly all evaporator air units cooling and, the next minute, have nearly all evaporator air units off. Refer to Chart 1.

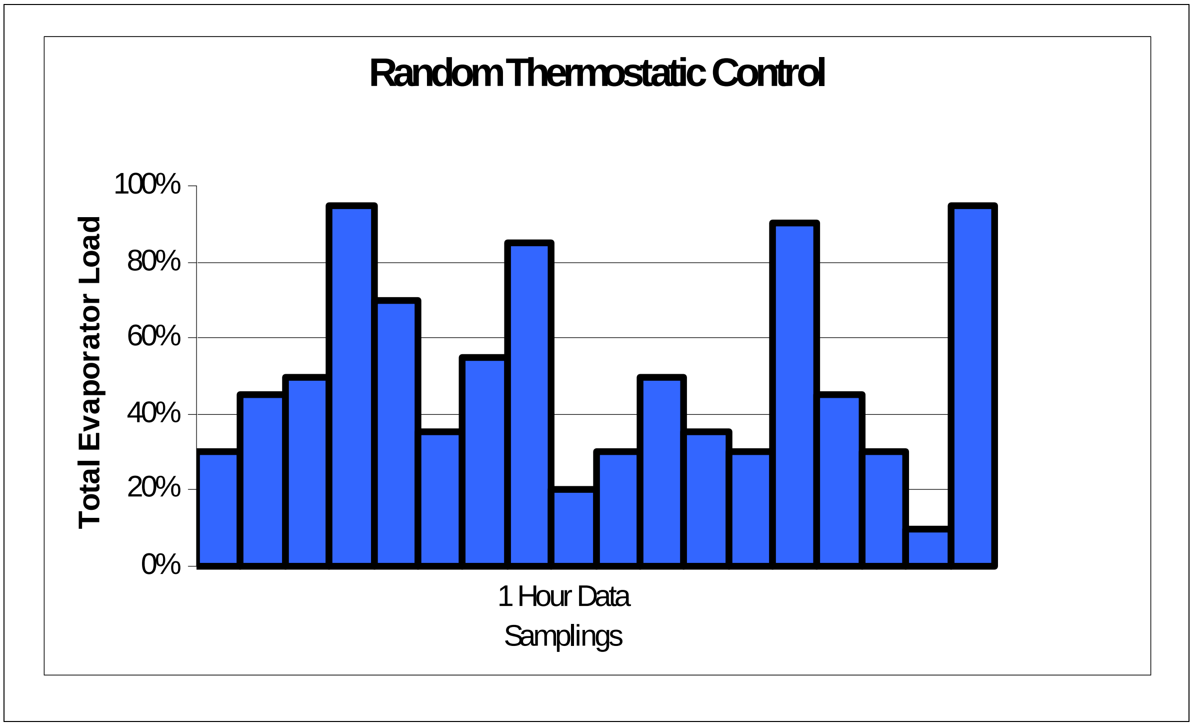
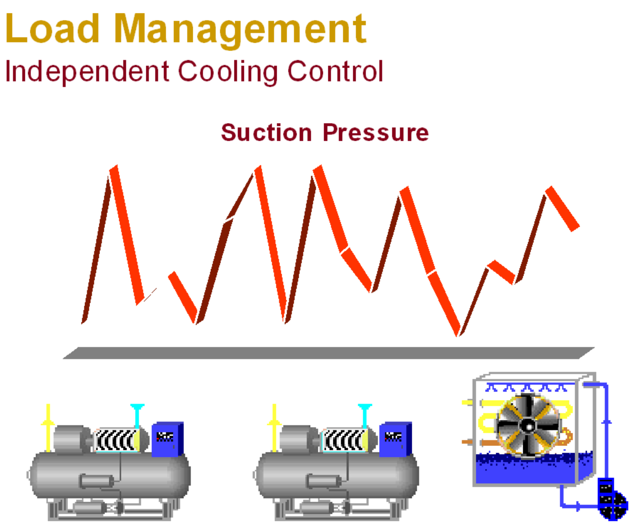


Chart 1 - Load Profile - Random Evaporator Control

These random and often volatile variations in refrigeration load that result from independent thermostat-type control produce erratic suction pressures and inefficient compressor and condenser (*Supply*) operation *(see adjacent graphic).*



Coordinated Evaporator Cooling Control

Refrigeration system stability and lower energy demand can be achieved with computerized controls that coordinate the operation of all evaporator air units across the entire facility. Through a logical prioritizing and ordering of cooling cycles, evaporator air units cooperatively “take turns” cooling. In this scenario, the least satisfied evaporator air units (i.e. furthest above their temperature control setpoint) are given priority over the most satisfied evaporator air units (closest to temperature control setpoint). The total cooling load can be allowed to slowly change as overall cooling demand changes. This coordinated approach greatly minimizes the volatile behavior of independent thermostat-type operation (refer to Chart 2), with no decrease in the amount of cooling provided, just an ordering of when the cooling takes place.

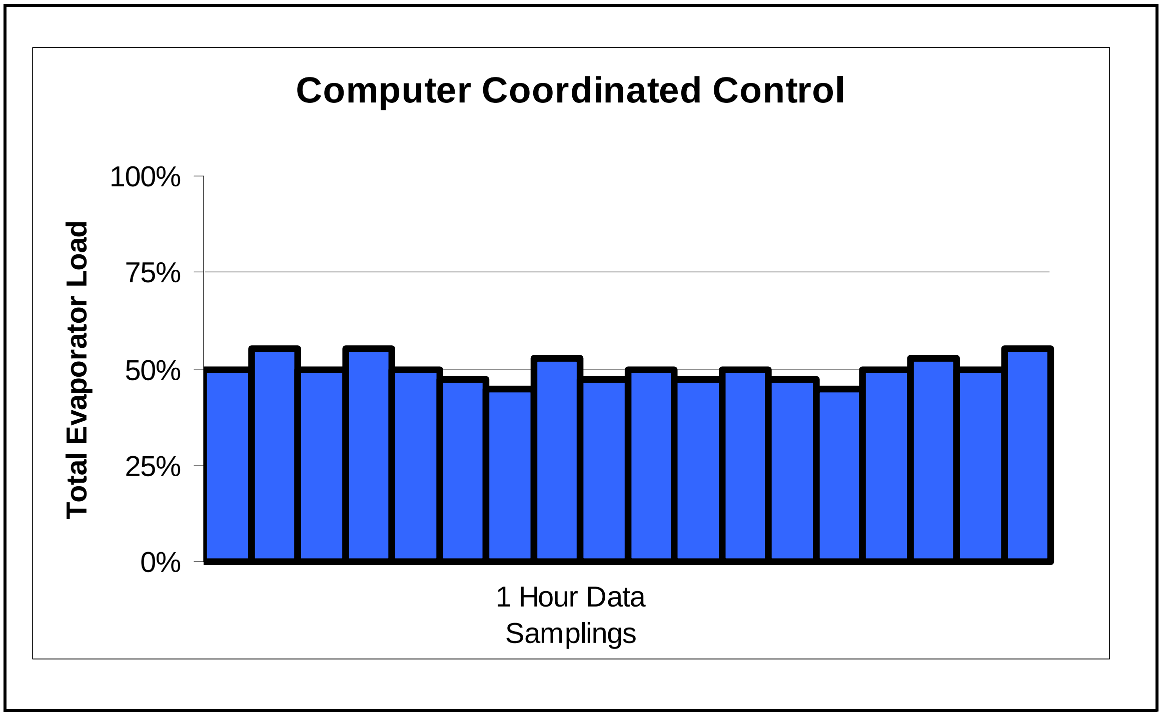
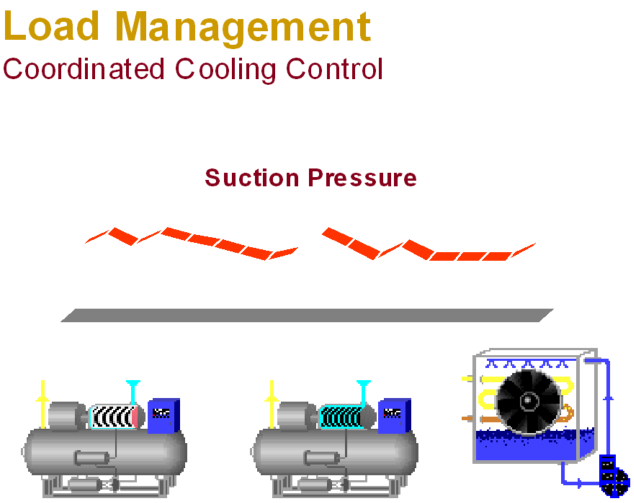


Chart 2 -Load Profile - Coordinated Evaporator Control

Because this coordinated approach stabilizes evaporator air unit loads, the refrigeration system as a whole operates with significantly greater stability and enjoys associated lower kW demand. This strategy also provides additional energy savings by allowing tighter control parameters on compressors and condensers.



Coordinated Common Room Evaporator Fan Control

A refrigerated room generally contains multiple evaporator air units. Conventional temperature control strategies using simple independent thermostats often result in unnecessarily high energy costs from uneven cooling. Substantial energy savings can accrue from coordinating fan operations of all evaporator air units in a given room, particularly when variable frequency drive (VFD) fans are installed.

Temperature Weighted Averaging

Evaporator air units can be coordinated using a whole room approach that employs use of multiple room temperature readings. This method deploys multiple temperature sensors in a zone (e.g., return & discharge air, remote room location air, product probe) and the calculates a single weighted average value used for cooling control purposes. For instance, room air temperature sensors located at far walls can be given less weight than a return-air temperature. Or a product temperature may overrule the weighted-average of the other temperatures. Additionally, a return air temperature sensor can be excluded while its evaporator air unit is warmed during defrosting.

The installation and weighted-averaging of multiple temperature sensors allow for the coordinated, or balanced, control of multiple evaporator fans in a common refrigerated area.

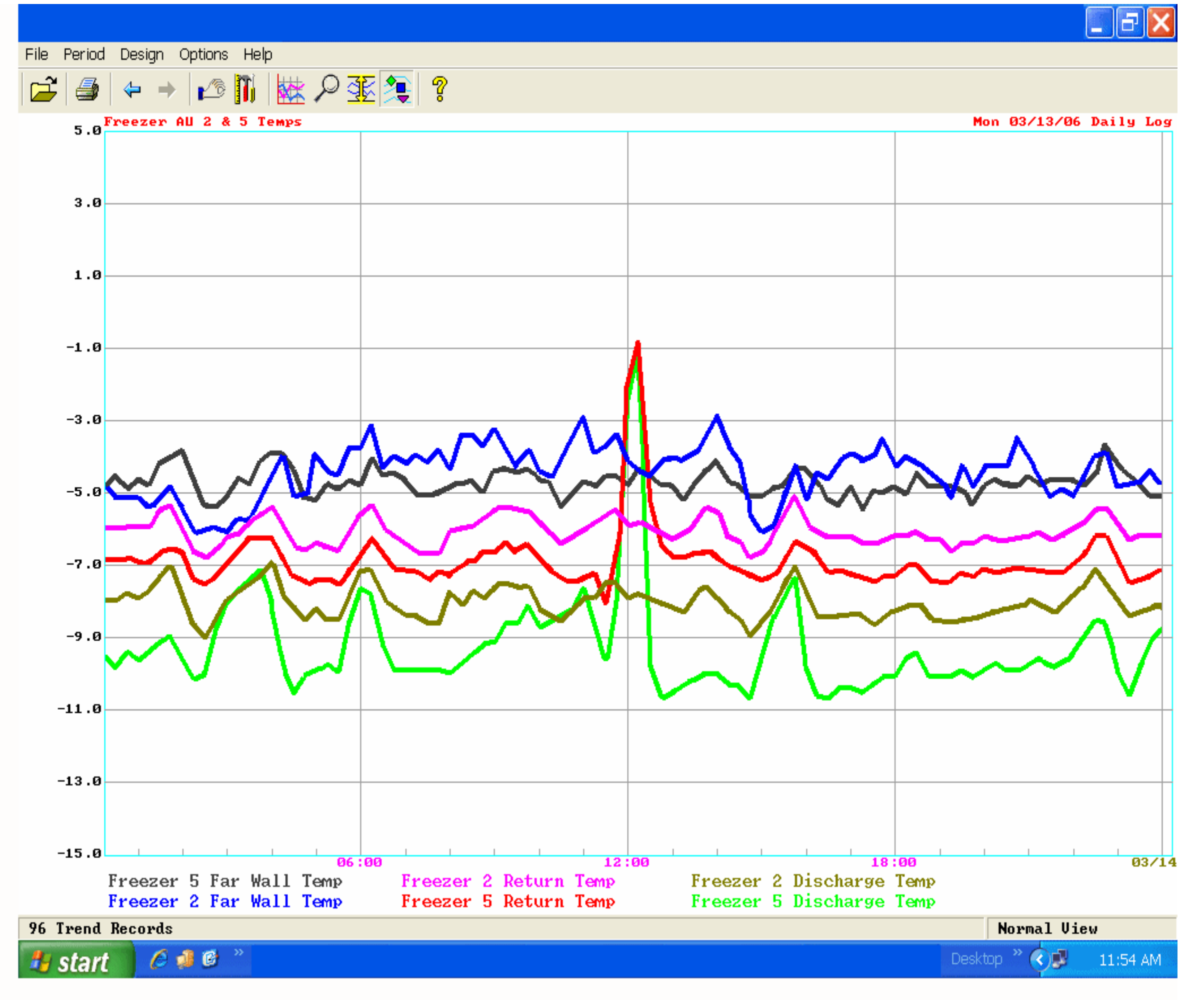


Chart 3. Plot of multiple air unit temperatures (Return, Discharge and Remote Room) for two air units. Note Freezer 5 Return and Discharge temperatures are ignored during defrost event at 12:00**.**

Balanced Fan Speed Operation

Conventional control strategies provide little in the way of managing multiple evaporator fans in a common refrigerated zone. Given that reduction in fan horsepower represents the single largest energy conservation measure available to the typical refrigerated warehouse, this represents a significant opportunity.

For example, a conventionally controlled room with two evaporator air units equipped with VFD fan motors could have one evaporator air unit's VFD fan operating at 100 percent speed while the other evaporator air unit's VFD fan is operating at 50 percent. This occurs in part because each evaporator air unit's operation *does* affect other evaporator air units as there is always some amount of "cross-cooling". Even a minute amount of load imbalance (such as one evaporator air unit's close proximity to a door or exterior wall) will cause an evaporator air unit under independent control to gradually increase its cooling. Cross-cooling would cause other evaporator air units to decrease their cooling. Other factors which contribute to load imbalance include defrost frequency, product type or activity and room shape. Invariably, these factors lead to one fan operating at maximum and the other at minimum speed.

While at first glance this might not appear to be a significant issue, upon closer examination, a number of problems arise. Because fan power is a function of its speed cubed, it results in an energy savings of 25 percent to operate both fans in the above example at 75 percent (see Table 1 below).

Unified vs. Independent Evaporator Fan Control							
Example #1	**Independent Control**				**Unified Control**		
Evaporator ID	Fan Speed	% Power *	Annual kWh		Fan Speed	% Power *	Annual kWh
1	100%	100%	6,656		75%	42%	2,808
2	50%	13%	832		75%	42%	2,808
Sum Totals:	150%	113%	7,488		150%	84%	5,616
Average Fan Power:		56%				42%	
Fan H.P =	**1.0**					**kWh Reduction:**	1,872
						% kWh Reduction:	25%

Table 1.

Other costly imbalances can occur with uncoordinated control of evaporator fans in a common zone. For example, the area cooled by the fan operating at 50 percent, and its liquid feed closed, might have air-mixing problems resulting in warm spots. Warm spots may be eliminated by the improved air circulation from unified fan speed control, assuming structural obstructions aren't the cause of poor air movement. Also, the evaporator air unit operating at 100 percent fan speed may not only have problems achieving its cooling objective, but it will also likely require more defrosts. And, since the 100 percent fan speed evaporator produces a large portion of the cooling, each of its defrost cycles will have a more pronounced effect on room air temperature.

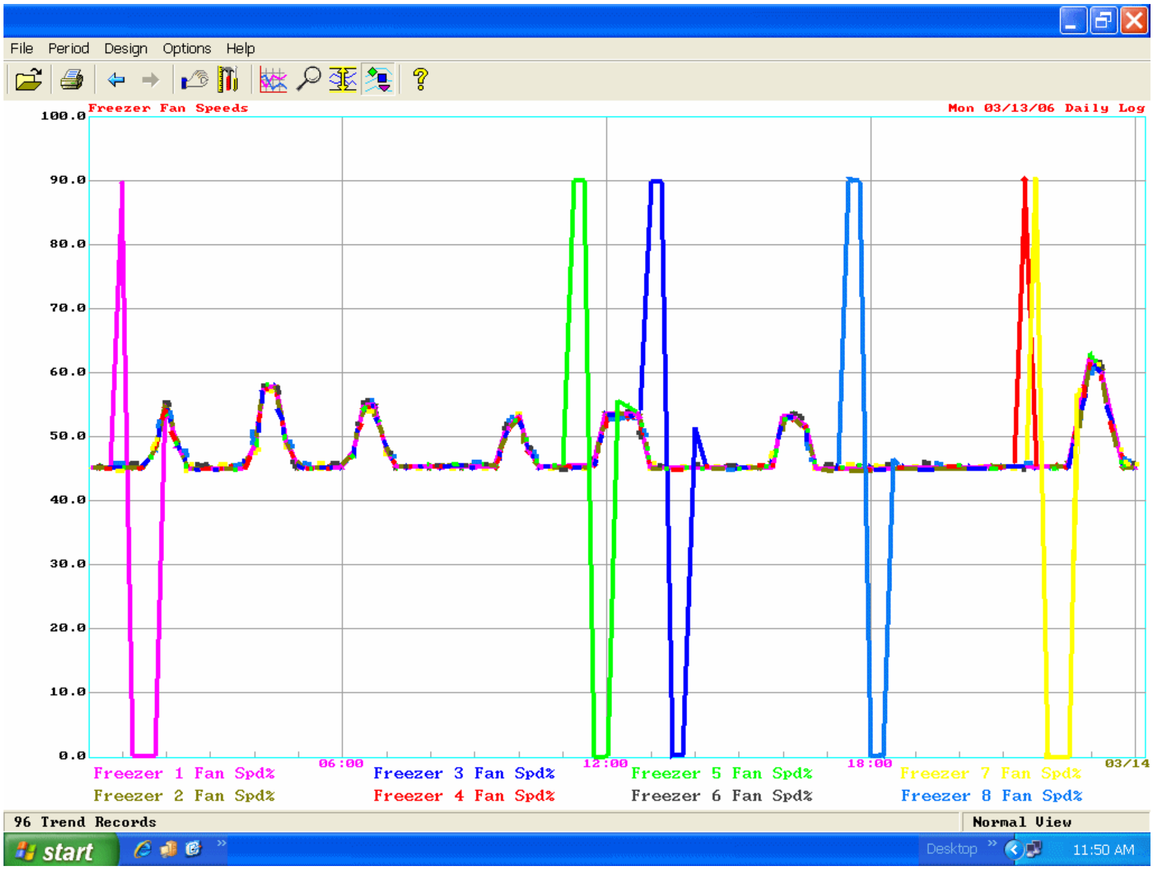


Chart 4. Plot of unified fan operating speeds for eight freezer evaporators. (Extremes are defrost cycles)

Other considerations of a unified room evaporator cooling approach vs. independent control include improved heat transfer efficiencies because the *total* heat exchange surface available in a given room is utilized. And although the control objective is to operate evaporator VFD fans in a common area at similar speeds, the strategy should allow for exceptions due to temporary load imbalances. Finally, evaporators with single-speed fans can also benefit by the increased ability to cycle fans off during moderate to low load conditions.

Unified vs. Independent Evaporator Fan Control							
Example #2	**Independent Control**				**Unified Control**		
Evaporator ID	Fan Speed	% Power *	Annual kWh		Fan Speed	% Power *	Annual kWh
1	100%	100%	6,656		63%	24%	1,625
2	50%	13%	832		63%	24%	1,625
3	50%	13%	832		63%	24%	1,625
4	50%	13%	832		63%	24%	1,625
Sum Totals:	250%	138%	9,152		250%	98%	6,500
Average Fan Power:		34%				24%	
						kWh Reduction:	2,652
						% kWh Reduction:	29%
						% Average Fan Power Reduction:	29%
Example #3	**Independent Control**				**Unified Control**		
Evaporator ID	Fan Speed	% Power *	Annual kWh		Fan Speed	% Power *	Annual kWh
1	100%	100%	6,656		60%	21.6%	1,438
2	50%	12.5%	832		60%	21.6%	1,438
3	80%	51.2%	3,408		60%	21.6%	1,438
4	50%	12.5%	832		60%	21.6%	1,438
5	50%	12.5%	832		60%	21.6%	1,438
6	50%	12.5%	832		60%	21.6%	1,438
7	50%	12.5%	832		60%	21.6%	1,438
8	50%	12.5%	832		60%	21.6%	1,438
Sum Totals:	480%	226.2%	15,056		480%	172.8%	11,502
Average Fan Power:		28%				22%	
Fan H.P =	**1.0**					**kWh Reduction:**	3,554
						% kWh Reduction:	24%

Table 2.

Energy savings realized from a unified fan speed control will vary by site depending upon the circumstances unique to each. However, energy savings with this strategy in a room with multiple evaporators equipped with VFD fans are generally 20 to 30 percent greater than that of independent, uncoordinated fan speed control. In fact, the chart above suggests that savings potential can be substantially higher, again, depending upon a site's circumstance. *(See the two examples in Table 2 above with four and eight evaporators*).

Multiple Fan/Air Unit Staging with Runtime Balancing

It is common practice that two or more evaporator air units may share a common valve group. This logical zone can be thought of as having multiple fans. Often these fans can be staged during light load conditions to reduce energy use. Operator-adjustable setpoints determine the minimum and maximum number of fans allowed to operate as well as a staging delay. To even fan runtime and frosting on an evaporator's coils, the order of operation is automatically rotated as determined by an operator-adjustable setpoint.

Load Shedding

Monitoring of plant electrical power demand, through a computerized refrigeration control system, can minimize power costs through the shedding, or removal, of qualified cooling load. However, cost savings vary widely depending on the strategy used.

Conventional load shedding strategies that simply restrict compressor operation often cause suction pressure to rise, and result in inefficient evaporator air unit operation. Other conventional load shedding strategies, utilizing simple “fixed shed” priority lists, can prove to be inadequate because they do not dynamically consider evaporator cooling requirements.

However, by coordinating both load *limit* and load *shed* settings with an evaporator air unit strategy, which will be described later in this paper, maximum energy reduction may be achieved. With this coordinated strategy, if kW demand exceeds the load *shed* kW setpoint, one or more evaporator air units nearest their temperature control setpoint (most satisfied) will shed load by limiting operation (fans stopped and refrigerant liquid supply valves closed). If kW demand falls below the Load Limit kW Setpoint, one or more of the evaporator air units furthest above its temperature control setpoint (least satisfied) will resume operation and restart cooling as allowed by a coordinated evaporator strategy. In other words, the evaporators that can most tolerate a shutdown will be turned off (shed) while the evaporator air units furthest from setpoint are the first to resume normal operation. Of course, a refrigeration load shed routine that doesn’t include measures to avoid product-loss risk will prove unacceptable.

Case Study

The beneficial effect of this coordinated approach is documented below in operating and power cost data derived from two comparable six-month periods in 2005 and 2006 at a large West Coast cold storage and seafood processor facility.

This facility consists of five large warehouses and 15 screw compressors, all under microprocessor control, furnishing 3600 TR and provides cold storage services year-round, plus refrigeration for seafood processing six months of the year, on a 12-hours-per-day / five-days-per-week basis. Because the plant has both processing and cold storage load, it effectively illustrates the benefits of treating power consumption of satisfied cold storage evaporators as an energy resource, which may be reallocated to other unsatisfied loads, in this case the processing load.

The chart below (Chart 5) shows how the processing load that commences at 6:00 am raises the Demand kW and triggers a Shed Load Mode as the demand kW exceeds the Load Shed setpoint. Coincident with these events is a storage area reduction in the "Allowed Air Unit Total Tons" and the attendant rise in "Desired Air Unit Total Tons". As illustrated on this daily chart, the electrical power that would have been used to maintain already satisfied storage loads is removed from them and redirected to the demands of the processing load.

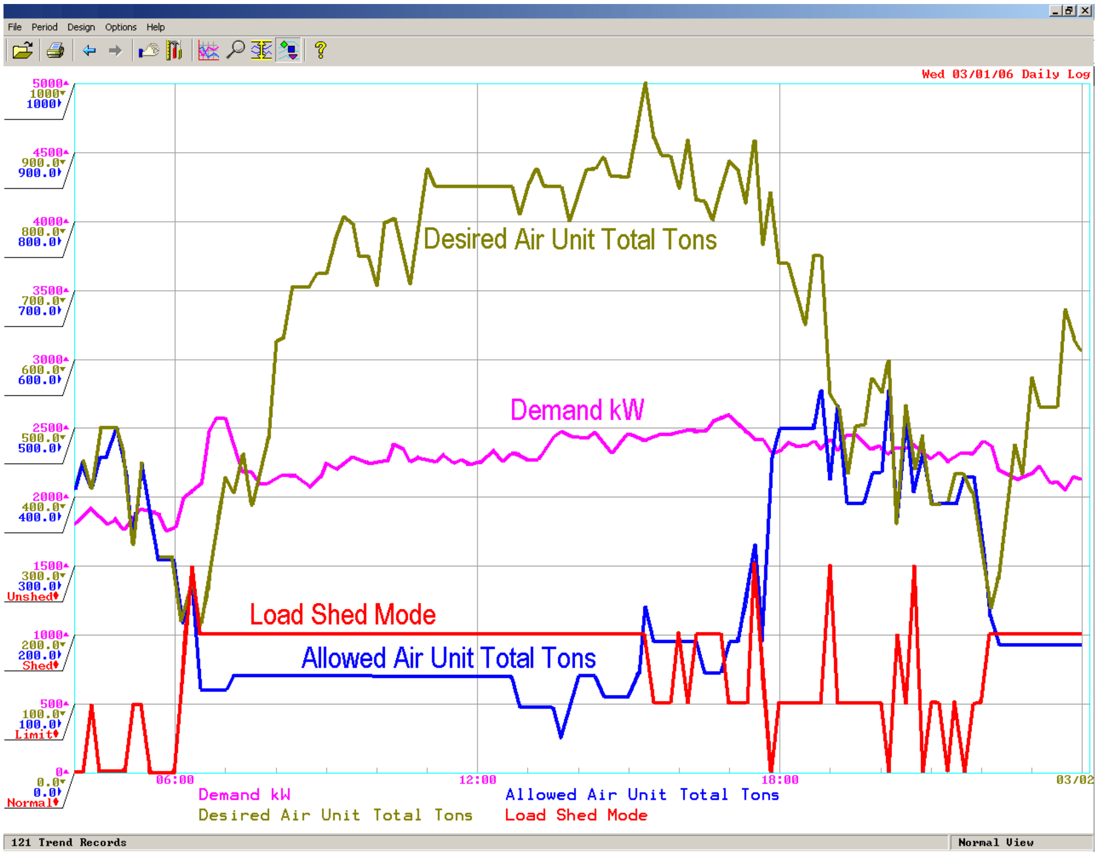


Chart 5 - Load Shedding in Action.

The aggregate effect on plant kWh is shown in Chart 6 where the January through June periods in 2005 and 2006 are compared because of their identical load conditions (2005 no Load Management, 2006 with Load Management). The actual kWh reduction due solely to the Load Management strategies of load shedding combined with coordinated evaporator control was 1,380,000 kWh yearly, or *12 percent* of refrigeration power. Another 1,400,000 kWh were saved from improved compressor capacity control. Significant power-cost savings also accrue from lowered peak demand provided by load shedding.

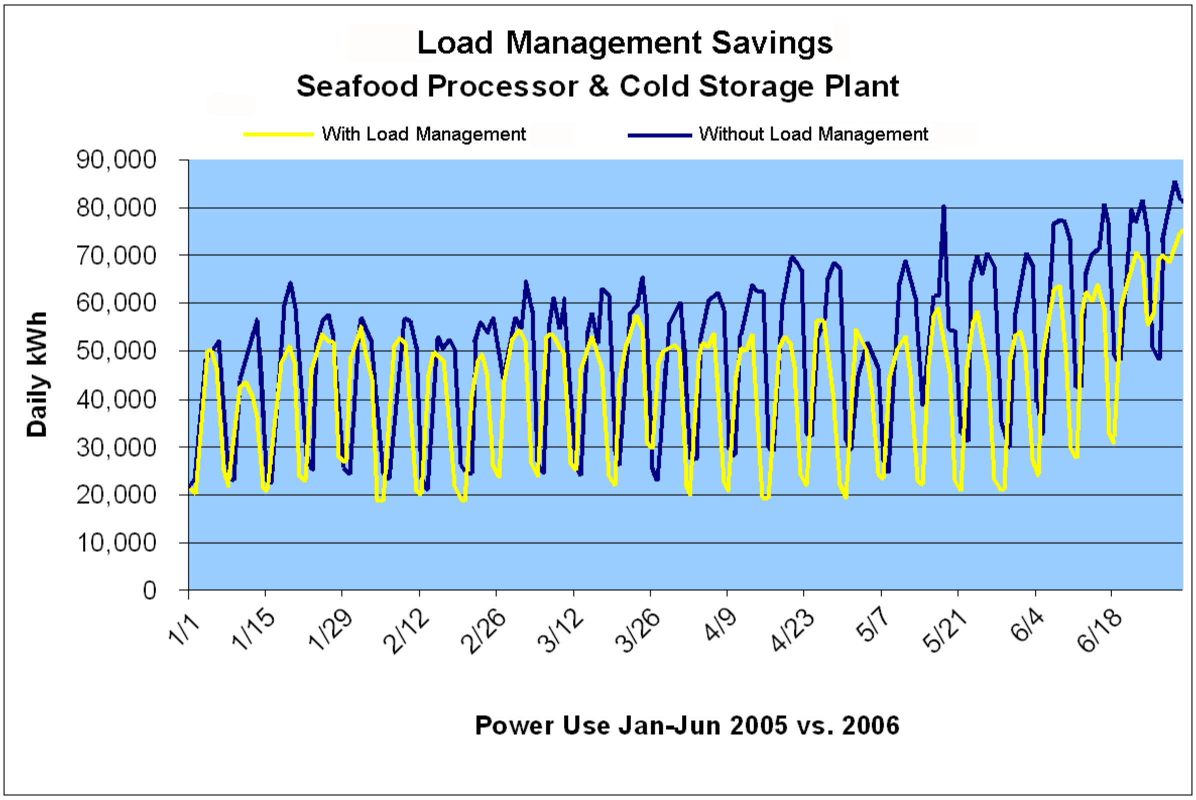


Chart 6. Warehouse daily energy use with and without Load Management controls.

The load shedding strategy should accommodate automatic adjustment to routine and special triggers such as aligning kW rates and corresponding load shed setpoints with time of day/day of week schedules, holiday-specific schedules, or in direct response to electrical utility company signals delivered through internet or modem connection.

Although we've discussed load shedding for continuously operating facilities, it can be expanded for aggressive applications where an entire refrigeration warehouse is shut down ("hibernated") for extended periods lasting a day or longer.

Conclusion

This whole-system approach, looking at all the variables in the plant and the coordinating equipment operation in response, is what distinguishes today's controls technology from less capable approaches of the past.

A Load Management control focus truly does more with less. And that's precisely what effective controls technology *should* do.

With the trend toward higher energy costs expected to continue, taking advantage of refrigeration control systems designed with the whole plant in mind makes dollars and sense for forward-thinking owners of cold storage and food processing facilities, and those who design, build and operate them.