

Cooling Tower Energy & Operating Cost Analysis Software

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Introduction

The Cooling Tower Energy & Operating Cost Analysis Software is an in-house program developed by Tower Tech and is used to design and evaluate the performance and life-cycle costs associated with a cooling tower. This version can be used to estimate the cost to purchase and operate a Tower Tech cooling tower and a competitor's tower. A number of assumptions about the details of the competitor's tower are made since detailed information may not be readily available. Also, a number of simplifying assumptions about both configurations and the operating conditions are made to reduce the scope of the problem. As such, the estimates of the costs accrued may not precisely reflect the customer's true cost, however, the relative magnitude between Tower Tech's and their competitor's tower should give an indication of the potential savings and allow the customer to make informed inquiries.

Configuration

Each patented Tower Tech Modular Cooling Tower™ contains a number of multiple-fan cells. The fans can be staged in a variety of ways or can be operated with variable-frequency drives. The table below shows a popular staging strategy with the use of a temperature controller on Tower Tech's line of factory-assembled cooling towers. In the energy analysis described below, the fans are either staged in pairs, or are controlled by a single VFD.

Temperature Controller
(Number of Operating Fans)

	Set point 1	Set Point 2	Set Point 3	Set Point 4	Set Point 5
2-Fan Tower Module	1	2			
3-Fan Tower Module	1	2	3		
4-Fan Tower Module	2	4			
6-Fan Tower Module	2	4	6		
8-Fan Tower Module	2	4	6	8	
10-Fan Tower Module	2	4	6	8	10

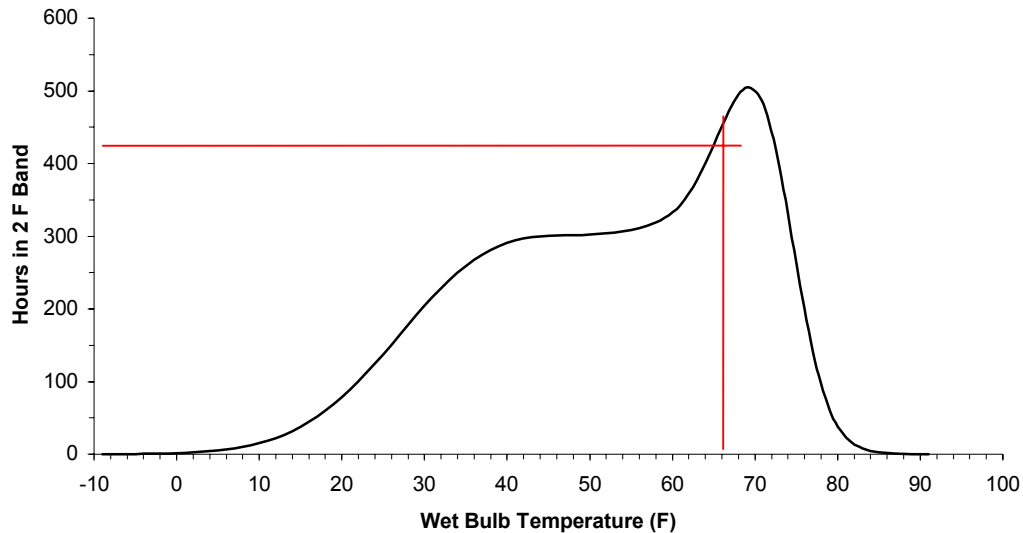
To simplify the analysis, it is presumed that there are as many pumps as there are cells and that the pumps are in parallel. Tower Tech's patented Rotary Spray Nozzle™ allows a variable flow to be run to the tower. Nozzle flow rates of 115 gpm to 350 gpm are possible, allowing the operator to maximize energy savings by distributing water to all available cells. In this analysis, water is distributed to all available towers without violating a lower limit of 115 gpm per nozzle.¹

A competitor's tower is modeled as a series of single-fan cells, each with either a single-speed or two-speed motor. It is presumed that there are as many pumps as there are cells and that the pumps are in parallel. It is assumed that a tower is valved out when a pump is shut down. This will maintain the same flow rate to the tower's nozzles.

Though the exact actual performance of the competitor's tower is unknown, a reasonable assessment of the tower's performance can still be made by modeling the tower as a combination of square cells with a total area equal to the footprint area of the Tower Tech tower. The competitor's fan diameter is chosen to provide the same total fan area as that provided by the Tower Tech model. The hub diameter is chosen to maintain the same hub-to-fan diameter ratio. A preliminary gearbox efficiency of 96% is chosen. An adjustment is then made to the efficiency so that the competitor's tower delivers 100% performance at the design point at the stated horsepower.

Ambient Conditions

Cooling towers are often sized to satisfy a point design. A narrow view of the energy costs at this single point, which may amount to only 100 hours of the year, may cost the owner significantly during off-peak operation. Shown below is the wet bulb distribution for the Oklahoma City area.² The graph can be read by first picking a wet bulb temperature on the abscissa. The ordinate then gives the number of hours per year that the wet bulb is within plus or minus one degree of that wet bulb. For example, there are approximately 425 hours that the wet bulb is between 64°F and 66°F. The form of the graph is typical for areas with four distinct seasons. There is a gradual growth in hours at lower wet bulbs, followed by a plateau and ending in a peak area that then declines to zero.



The energy analysis described here takes into account the variation in wet bulb temperature throughout the year. Since at times the ambient wet bulb temperature may be greater than the design wet bulb temperature, it becomes necessary to modify the method of analysis. As wet bulb rises above the design load condition, it becomes necessary to increase the cold water temperature. To simplify the analysis, the cold water temperature is held fixed and the wet bulb temperature is artificially altered. All wet bulbs that are greater than 2°F less than the design cold water temperature are replaced with that temperature. These points are then recorded as having fallen short of the design load. The evaporation rate that results from this modified approach are typically slightly less than what would occur if the cold water temperature was allowed to rise. As such, actual water use may be slightly higher than predicted.

Operating conditions

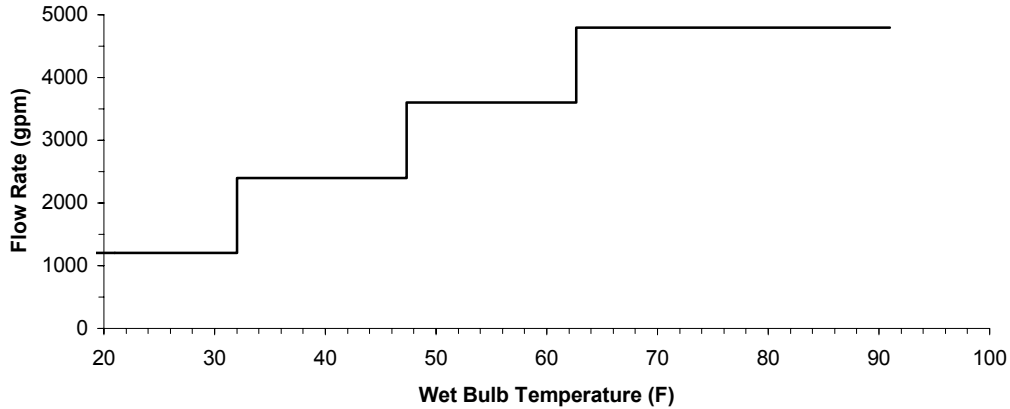
The input to the energy-analysis software consists of three components, the number of cooling towers, the flow rate, and the heat load. The heat load is modeled by a combination of a constant-process load and a variable load. The variable load might be a chiller load that decreases incrementally as the wet bulb falls. It is assumed here that this incremental load is directly tied to the number of cooling tower cells and the

number of pumps. For example, five chillers are cooled by a five-cell tower that are supplied with water by five pumps.

It is common to vary the flow rate to the cooling tower as the load changes. Here it is presumed that there are as many pumps as there are cells and that the pumps are in parallel. Since the fraction of the pump head that can be attributed to viscous effects may not be readily available, the variation of viscous losses with flow rate are neglected and a linear relationship between the number of pumps and the flow rate results. Two inputs are required to define the variation in flow rate, the maximum flow rate and the number of pumps in operation at the winter-operation condition.³ It is assumed that the pumps are shutdown in even increments in wet bulb temperature between the design wet bulb and the onset of the winter-operation mode. If there are N pumps and N_w pumps in operation at winter load, then the pumps are shut down in even temperature increments of

$$\Delta T_p = (T_{WBD} - T_{wo}) / (N - N_w).$$

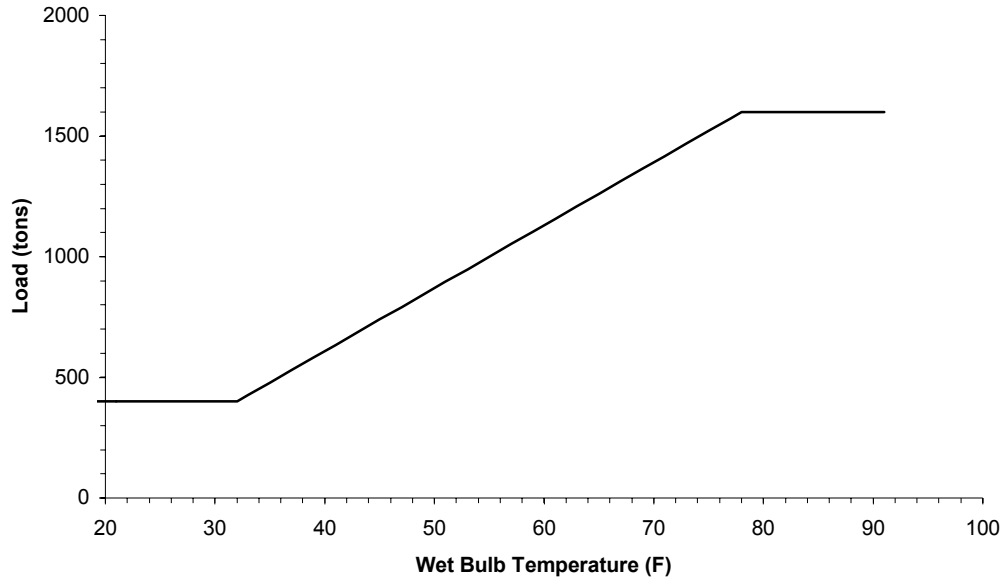
If a four-cell tower has a summer-load flow rate of 4800 gpm, a design wet bulb of 78°F, and one pump in operation at winter-load conditions, then the flow rate distribution displayed below results.



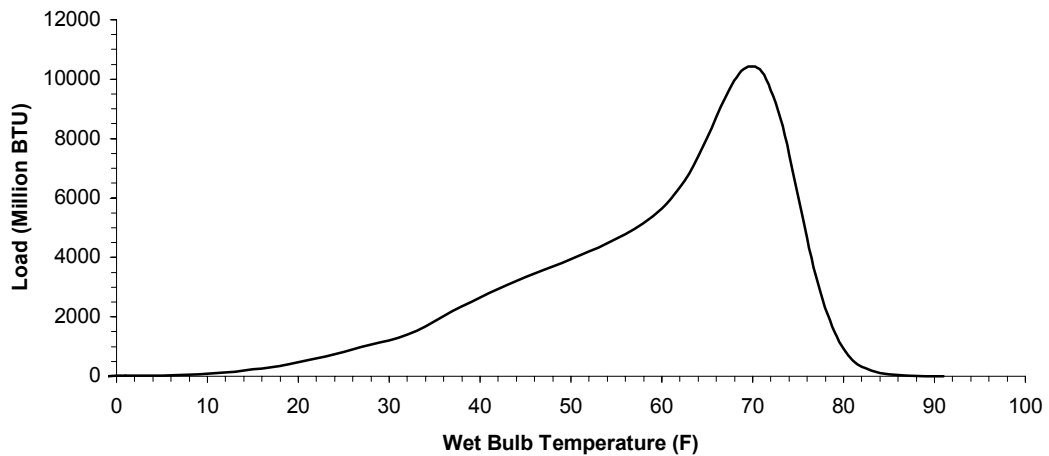
The heat load distribution is defined by three inputs, the minimum and maximum load and the design wet bulb. The two loads may be identical for a constant heat load process. Alternatively, the minimum load may be defined as zero if the tower is taken out of operation for a portion of the year. The heat load is held fixed at the maximum value for all wet bulbs greater than the design temperature. The load is held fixed at the minimum load for all temperatures below the winter-operation temperature. In between the two extremes, the heat load distribution is assumed to vary linearly with wet bulb temperature. That is,

$$\dot{Q} = \dot{Q}_{\min} + (\dot{Q}_{\max} - \dot{Q}_{\min}) \min \left[1, \frac{\max(0, T - T_{wo})}{T_{WBD} - T_{wo}} \right].$$

Depicted below is a heat load distribution that was generated for a tower with a 1600 ton summer load and a 400 ton winter load at a design wet bulb of 78°F.



The actual heat removal that occurs at a specific wet bulb temperature is the product of the heat load and the number of hours of operation at that wet bulb. A graph of the heat removal versus wet bulb for the heat load displayed above and the wet bulb distribution for the Oklahoma City area is displayed below.



Though the heat load and wet bulb may drop throughout the year, the load per tower may actually increase if too many cells are shutdown. Consequently, the analysis may uncover operating conditions during off-peak heat loads where the towers are short.

Cost Analysis

The prudent customer realizes that there are a variety of costs associated with the purchase, operation, and maintenance of a cooling tower. An attempt to quantify these costs is outlined here.

Pump Costs

The ripple-down effect of a savings in pump head should not be overlooked. A reduction in pump head may correlate to a reduced cost of piping materials and installation labor, a reduction in pipe maintenance time, a reduction in floor space to house the pumps, etc. These costs will be ignored, but we do include the initial savings in pump cost. Depending on where the flow rate and pressure rise land on the pump curves for the available pump line, a reduction in pump head may equate to a reduction in pump size. As a minimum, a reduction in impeller size is possible. The semi-empirical equation displayed below is used to estimate the initial savings in the cost of pumps.⁴

$$\text{Pump cost} = \$2500 N_p \sqrt{GPM / (3954 N_p \eta_m \eta_p)} \sqrt{\Delta h}$$

Here, N_p is the number of pumps, η_m is the motor efficiency, η_p is the pump efficiency, and Δh is the total system pump head in feet (process + tower rise + nozzle losses).

The potential savings can best be realized with an example. Assume four pumps each provide a flow of 1200 gpm to four 400-ton towers. The pumps operate at 80% efficiency and are driven by 85% efficient motors. If the process pump head is 30 ft, the competitors pump head is 20 ft, and the Tower Tech pump head is 10 ft, then there is a potential initial cost savings of \$5,000. Actual savings may be significantly less or more than this, depending on where the design operating point falls in the manufacturer's pump line.

An additional pump cost may be accrued if the number of pumps used for each tower is different. Typically, a fewer number of larger pumps will be cheaper than more smaller horsepower pumps. This cost differential is estimated and added to the total tower cost.

Pump Energy

Tower Tech has minimized pump energy requirements by taking a three-pronged design approach, reduction in losses through the nozzle, reduction in the height of the nozzle spray zone, and removal of the free-fall zone above the basin. The Rotary Spray Nozzle requires less pressure head to atomize the flow since the turbine in the nozzle is a much more efficient device than the atomization approach used in a conventional nozzle. Also, by adapting a lateral spray pattern, the nozzle exhaust can be placed a mere three inches off of the tower fill.

Tower Tech's removal of the free-fall zone above the basin was another major design improvement. This zone is required on a conventional tower to permit airflow into the fill. Unfortunately, from a thermal perspective, this is a very inefficient portion of the cooling tower. The cooling achieved in one foot of fill can be more than the cooling in ten feet of free-fall water. This is a very ineffective use of pump energy.

The pump energy costs can be approximated with the equations displayed below.

$$HP = GPM \Delta h / 3954 \eta_m \eta_p$$

$$\text{Pump Energy Cost} = 0.7457 k \text{ hr } HP$$

Here, HP is the total pump horsepower, hr is the number of hours of operation, and k is the dollar cost per kilowatt-hour. If an 80% efficient pump driven by an 85% efficient motor pumps 4800 gpm through 50 feet of head, then 89 hp is utilized. If energy costs are 3.3 cents per kilowatt-hour⁵ and the pump is run continuously year-round, then the pump energy costs are \$19,300 per year.

If a Tower Tech tower is replacing an existing tower with pumps sized to the larger pump head that was previously in place, it may be necessary to trim the pump impellers to fully realize these cost savings.⁶

Chemical Treatment Costs

The cost associated with the proper treatment of a cooling tower's water should figure heavily into the decision to purchase a manufacturer's tower. Potential savings in chemical costs arise from two primary areas, a reduction in chemical treatment requirements and a reduction in chemical waste in drift and blowdown. The reduction in chemical requirements for the Tower Tech design is a consequence of the enclosed, self-cleaning basin. A reduction in algaecides will result since the basin water is not exposed to sunlight. In addition, the enclosed basin significantly reduces the amount of dirt and trash that is typically blown into an open basin. The self-cleaning nature of the Tower Tech basin also eliminates the build-up of sludge, common in stagnant regions of most towers. Bacteria, such as Legionella, can remain protected from chemical attack under this sludge. Additional chemical treatment (and cost) alone may not sufficiently remove these bacteria so additional basin agitators and filters may need to be added to the competitor's cost estimate. These costs have not been included in this analysis.

The cost to maintain the chemicals in the tower is assumed to be proportional to the tonnage,

$$\text{Maintenance chemical cost} = \$6 \eta_{ch} \text{ tonnage} \frac{\# \text{hours}}{\text{yearly operating hours}} .$$

Here, η_{ch} is a correction factor to account for the cost savings associated with a Tower Tech tower. The primary savings will likely be due to a reduction in algaecides and possibly biocides. Here a correction factor of 1.0 is assumed for the competitor's tower and 0.8 for the Tower Tech tower. For a 1600 ton load, a conventional tower may require \$9,600 per year in chemicals. Annual savings of \$1,900 might be realized on the Tower Tech design.

Since chemicals that are lost in drift and through blowdown must be replenished, additional savings can be achieved if both these sources of waste can be reduced. The loss of water through drift and blowdown is tracked while the detailed fan-energy calculations are being made. The additional cost is simply the cost to treat the portion of the makeup water associated with drift and blowdown replacement,

$$\text{Replacement chemical cost} = \$0.004 \times \text{waste gallons}$$

Here, a treatment cost of \$4.00 per 1000 gallons of tower water is assumed. Drift-loss is discussed in more detail in the next section.

While chemical costs associated with drift can be large, the loss of chemicals through blowdown can be orders of magnitude greater. Significant chemical and water savings can be realized if higher cycles of concentration can be run in the tower. Since the enclosed Tower Tech design is less sensitive to swings in ambient conditions, it is less difficult to maintain levels of concentration in the tower. As such, if higher cycles of concentration can be run, a significant reduction in chemical costs will occur. Here we assume that the cycles of concentration run on the Tower Tech tower is 50 percent greater than that run on the competitor's tower. As always, all tower water treatment plans should be rigorously tested and maintained by a qualified water treatment consultant.¹ The blowdown required can be computed with⁷

$$\text{Blowdown} = \frac{\text{Evaporation}}{\text{Cycles} - 1} .$$

Fan Energy

Two-speed motors are an effective means of fan-energy savings and are in common use. Tower Tech has taken the approach of using a greater number of smaller diameter fans driven by single-speed motors. This makes motor replacement cheaper and the increased number of fans typically doubles the number of fan set points, allowing the fan power to more closely match the changing load.

The fully enclosed high velocity Flow-Thru Basin™ on the Tower Tech design is made possible by the patented Water Collection System™ above the fans. There is a higher pressure drop through these collectors than through a conventional tower's louvers. Consequently, the Tower Tech model may have slightly higher horsepower requirements at the design condition. However, at off-design conditions there can be significant energy savings by effectively managing the water distribution to the tower.

Reduced loads and low wet bulbs during winter operating conditions equate to very little energy use. The real savings that are achievable with water distribution management occur during spring and fall conditions. At these times, the load requirements are still relatively high, but a reduction in wet bulb allows towers to be shut down and/or a few fans to be cycled off. During these slightly reduced load conditions, which amount to the majority of the operating year, energy savings can be accrued by spreading the reduced flow rate to available towers. Spreading the flow over more surface area allows for lower fill velocities and a resulting reduction in fan power requirements. This is only possible because of Tower Tech's Variable-Flow Rotary Spray Nozzle™. The nozzle maintains the same flow pattern as the flow rate varies, preventing a severe degradation in tower performance. This allows the user to effectively use the fill that was purchased to meet the design requirement, but that often remains idle for a majority of the year.⁸

If a variable frequency drive is used, the required horsepower is incremented by three percent of the rated tower horsepower to account for losses in the VFD. For example, if a tower with total available power equal to 60 hp is run at half speed to meet a specific duty, then the tower will pull $30 + 1.8 = 31.8$ hp.

Water Costs

The cost of water is a frequently overlooked expense associated with the operation of a cooling tower. Not only is water needed for makeup and to replenish blowdown and drift losses, but the cost of disposal must be accounted for. Water from a natural source might be used as the tower supply, but additional water treatment costs may be accrued, a reduction in cycles of concentration may be necessary, and special monitoring of the affluent may be required to satisfy EPA requirements. Even if a free water source is available, it is unlikely that the cost of treating and disposing of the waste water will be totally eliminated. A state-by-state approximate cost to purchase and dispose of water is used if accurate local data is not readily available.⁹

The evaporation from the tower is tracked as the detailed fan-energy analysis is run.¹⁰ Added to this volume is the drift loss, which is composed of losses through the drift eliminators and from the louver area on the competitor's tower. Drift eliminator losses are generally negligible if the drift eliminators are in good condition and installed correctly.¹¹ Losses in the louver area of the competitor's tower are common, but remain to be quantified. Early data suggests that there is a reduction in drift from the Tower Tech tower due to the low exit velocities and elimination of drift in the louver area. For this analysis, the drift loss of a conventional design is taken as ten times the loss from the Tower Tech design. Typically, these losses amount to only a few percent of the losses due to blowdown.

The last component of water usage is the blowdown. As is typical, the blowdown is assumed to track with the tower evaporation rate.¹² It is common to see cycles of concentration as low as two or three in a conventionally treated tower. As previously mentioned, it may be possible to run a higher cycle count in a

Tower Tech tower since swings in the tower chemistry can be more easily controlled. The cycle count of the Tower Tech tower is assumed to be 50% greater than the competitor's tower.

If a 400 ton tower with a flow rate of 1200 gpm has a yearly-average evaporative makeup need of 0.8%, has drift and louver losses, and maintains four cycles of concentration, then there is water use of 9.6 gpm for evaporation, 0.2 gpm for drift and, and 3.2 gpm for blowdown. At a water cost of \$1.50/1000 gal and a disposal cost of \$2.00/1000 gal, this equates to a yearly water bill of \$13,600.

FOOTNOTES

- 1 A reduction in water flow to a tower may lead to accelerated scale buildup. Tower operators should check with a qualified water consultant to fully evaluate the local water system and the water quality management program planned for the tower. The flow rate to the tower should not be decreased below the determined minimum operating condition.
- 2 The wet-bulb-distribution data used in this energy analysis were generated from a set of data from *International Station Meteorological Climate Summary, Ver. 3.0*, Federal Climate Complex, Asheville, March, 1995. Most of the data for US cities is an average over 50 years. There are only ten or fifteen years of data for some of the overseas cities. The typical data set consists of a monthly average and standard deviation of wet bulb for three-hour increments. These eight monthly data points over 12 months were used to generate the number of hours per year in each of 80 two-degree increments in wet bulb between -40°F and 120°F. A normal distribution of wet bulb temperature was assumed for each of the 96 three-hour-increment data points.
- 3 The winter-operation condition is defined as tower operation at a fixed minimum number of cells, flow rate, and load. Typically this is defined as operation at temperatures at or below 40°F.
- 4 A specific gravity of 1.0 is assumed in this equation and throughout. Efficiency of the pump and pump motor is assumed identical for both the competitor's and Tower Tech's configuration.
- 5 An approximate cost of electricity is used in the analysis if accurate local data is not available. This data is from *Energy User News*, Vol. 21, No. 3, March 1996.
- 6 If a tower with reduced pump-head requirements replaces an existing tower and the pump impeller is not resized, then two possible scenarios may result. If a throttling valve is not adjusted, the flow to the tower will increase. In the high-efficiency portion of the pump curve, a 20% decrease in tower pump head will roughly equate to a 20% increase in flow rate. The tower could reject more heat, but via a lower range. If the flow is to remain fixed, a throttling valve must be adjusted. The concomitant head loss that results will negate any potential savings.
- 7 See: *Betz Handbook of Industrial Water Conditioning*, 9th Edition, Betz, 1991.
- 8 The performance of a cooling tower is primarily driven by two quantities, the air-water surface area and the relative velocity between the air and water (which drives evaporation rate). Performance increases roughly linearly with both fill area and fill velocity. However, fan power varies as the third power of velocity. When fill area is doubled, fill velocities can be roughly cut in half. The power required to deliver the same performance is cut to one eighth on each cell. Since twice the number of cells need to be operated (to double the fill area), the total power needed is reduced to one-fourth the initial value. Actual savings may be greater than this since the reduced water loading decreases the pressure drop through the fill.
- 9 *Ernst & Young's 1994 National Water & Wastewater Rate Survey*, Ernst & Young LLP, 1994.

- 10 This makeup need should be similar for both the competitor's and Tower Tech's design. Differences can be traced to variations in approach between the designs since both designs will not track the load identically. (As the approach is reduced, the fraction of heat removal attributable to sensible heat transfer decreases.)
- 11 A Brentwood CDX-150-type drift eliminator is used in this analysis. There is a slight variation in drift with flow rate, but here a constant fraction of 0.0014% of water flow rate is used. See: *Brentwood Industries, Inc. Drift Eliminator Test T91-52, Volume I*, January 29, 1992.
- 12 Substantial savings can be accrued if evaporative make-up water is tracked since water lost through evaporation does not have to be treated as sewage. Typically, a certified meter must be installed to track this usage and a credit is given to the customer.