

Evaluate Your Cooling Tower

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By

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It is the purpose of this paper to show a few simple methods to determine the best way to arrive at the most economical cooling tower selection for a project.

Low first cost may not be the best method for selecting a cooling tower. Power consumption for pumps and fans, the cost of the basin, piping and electrical equipment, and the choice of tower layout should often be the deciding factors. Optimization of tower design conditions related to other equipment such as heat exchangers and condensers is discussed.

This paper evaluates options of present worth value, annual cost and capitalized costs of revenue streams, projected life span, return on investment, depreciation, taxes, general administrative expenses, insurance requirements and the cost of power, and it provides comments on the proper choice of decision making formulas.

It is well known that only a few specific items are needed to select a cooling tower, such as the water flow rate, the hot water temperature, the cold water temperature, and the wet bulb temperature. Generally, when we are called for a selection, the engineers and purchasing agents contacting us are sophisticated enough to know these basic requirements.

One can only hope they have considered what one degree colder water would do to the overall plant capability and profitability. Also, it is not always the most economical to choose the highest recorded wet bulb temperature. It is usually desirable to investigate the optimum balance between the cost of the cooling tower and the heat exchangers or other equipment it is cooling. The concept of alternate design temperatures is presented here just to provoke thought on the possibilities and the effect they may have on the overall plant economics. Although these are important concepts they will not be detailed in this paper.

In reality we often really need more than just the temperatures and flow rate. We need to know what power is worth, and this becomes a major stumbling block since the engineer and purchasing agent probably have not discussed it with management or even mentioned to management that power will be consumed as well as generated or it is needed to make a product. The reactions we get are from denial to "what you are talking about? Why do you need to know that?" We need to know it because it may make a big difference on the price or the plot space required.

There is a natural tendency to take bids and pick the low price. That may or may not be the best approach for your project. There may be a very significant long term savings for the project if the economics of operation and cost of capital are investigated.

Why evaluate?

First, the need for the analysis and the effect that it can have should be demonstrated. Many of the projects proposed for cogeneration, ethanol or other chemical plants and refineries just happen to fall in a size where many different types of cooling towers are available. These can range from crossflow to counterflow, from packaged factory assembled towers to the small or large field erected towers. A great variety of products are available for your consideration: almost too many. Larger power plants can be air cooled, either by direct or indirect steam condensation, or water cooled with mechanical or natural draft cooling towers, and to a lesser extent, rivers and the oceans. Refineries, high rise air conditioning and other projects usually use cooling towers.

Evaluating a power project, as compared to evaluating a chemical or refinery project, often requires a major adjustment in conceptualizing for both project engineers and managers. For a high rise office building the cost of energy is necessary to retain the tenants. In a refinery electrical consumption is often considered a cost of producing the product. In the power industry electricity *is* the product. It may be a surprise that cost of operating the central plant in a high rise building complex can be one-third of the total cost of operation of the entire building. Current politics regarding “greenhouse gasses” has stirred considerable pressure to reduce our energy requirements. More than ever it is necessary to look at all of the equipment in the plant or building cooling loop to try to make improvements.

Power consumed in operating a power plant is obviously non-productive. You can either use it, or you can sell it. For some cogeneration projects the power consumed is purchased from the local utility and the power generated is sold to your client. The two can be at different rates. There are significant variations on the method of establishing a power contract, and it is not the intent of this paper to evaluate the various contracts. We are more concerned with the effect on selection of equipment and plant layout and how they might affect the project.

What is energy worth?

Energy rates can be found on the internet. Energy Information Administration (EIA) posts rates for residential, commercial, industrial and transportation categories monthly for every state. April 2007 kilowatt-hour rates (*cents per kW-hr*) for a few locations are tabulated below:

State	Commercial	Industrial	All Sectors
Connecticut	15.75	13.02	16.58
Hawaii	19.91	16.36	19.26
Missouri	5.57	4.29	5.78
Idaho	4.82	3.32	5.15
U. S. average	9.28	6.16	8.77

In addition to the \$/KW charges there can be demand charges to offset the peak power requirements the plant may need for hot days or other conditions.

However, we are not talking pennies. Here are examples of power consumption over time using the U. S. average cost of industrial power (unadjusted for inflation-8,000 hours per year).

	Power Consumed (KW)	10 years	20 years	30 years
10 fans for a geothermal power plant cooling tower (150 KW per fan)	1,500	\$7,392,00	\$14,784,000	\$22,176,000
Pump cost for 1 ft (0.3 m) of pump head for a 50,000 gpm (11,500 m ³ /hr) cooling tower (total tower pump head 24 ft – 7.3 m) or 4.2%	11.2	\$55,200	\$110,400	\$165,600

Do you select a big tower or a little tower?

The cooling tower doesn't set the heat load. The plant sets the heat load, and in order to do the cooling duty you can be provided with a big tower that does not use much power or a little tower that uses a lot of power. The tower can be tall with little plot space or short with a lot of plot space with resulting variations in pumping costs. The fans can be efficient or cheap. The variations can be dramatic. *However, they can all be designed to do the same required cooling duty.* So, which one should be selected?

Selecting the evaluation tools

It is not believed necessary to be sophisticated, at least in the early stages of the project. You need to establish the cost of power consumption which may well be the same as the selling price for your locality or the value in your power contract. Next, it is necessary to consider the cost of capital, which can be considered your overall corporate cost of capital, the cost of borrowing money for this project, the inflation rate plus a percent or so, or the marginal return that you could get on your money if you did not invest it in the project at all. Third you need to establish the duration of the analysis. It is also necessary to consider variations on how the equipment will be used.

There are several methods of analysis which can be used. The method used (*present worth, annual cost, or capitalized cost, discounted cash flow rates of return, payout period, or present worth combined with a capital recover, etc.*) does not make much difference in the final analysis. *Annual cost* and *capital cost* methods make use of levelizing techniques, which employ present worth analysis either directly or indirectly. Management sometimes prefers the *annual cost method* because they can relate it to flow of funds,

As will be demonstrated later it is necessary to adjust the initial cost of capital to include a return on the investment you are making and to account for annual fixed expenses. The adjustments need to be brought to “present worth” values and compared to the energy consumption to get a true comparison of one alternative to another. The method used for

analysis probably has more to do with the personality of management than the actual method used. What is important is to get the understanding that some consideration must be made for the perpetual conflict between capital cost and power consumption. Once the necessary information is obtained the easiest methods to use to evaluate equipment is a combination of “capital recovery factor” and “present worth”. This paper will explain the process to obtain that information and reduce it to a few simple factors that can be used to facilitate the analysis of which cooling tower or tower component is best for your plant.

What is the evaluation period?

Are you going to operate the plant for a full 30 years, and you will be the owner? Have you signed a power agreement for 30 years but you're really an investor looking to make a quick buck and take advantage of the current tax laws. Maybe you really plan to unload the plant to somebody else in about 5 years so they can write it up again and start the depreciation all over. Are you a tax paying entity or are you part of a public institution that has no tax advantages? How many hours a year do you expect the project to operate considering downtime for maintenance? That new high rise building in downtown is supposed to last well over 100 years (I saw one in great shape in Brussels Belgium with a corner stone dated 1492), so how long are you going to design yours for? Casinos in Las Vegas are never designed for over 15 years – they tear them down and build something bigger.

Historically power projects are evaluated over a period of 25 to 30 years with the normal being 20-25-30 years of operation. Petroleum and refinery projects are generally evaluated on a 7 or 8 year period with typical economic evaluations being made on 3 to 5 year payouts. Why is this? I guess I wondered why for a long time, and I finally determined in a conversation with one of my banker friends that the banks would only loan monies to a chemical or refinery project for 7 or 8 years, and since it takes 3 or 4 years to build the plant they are only allowed 3 to 5 years to pay it out. If you cannot pay it back in the required payout period, the project is not viable. The banks will not loan you the money. Recent research of projects on the internet and talks with bankers revealed loan durations for power plants and large buildings are about 30 years. Cogeneration, ethanol plants, geothermal and general industry loans appear to be about 10 to 15 years, but there are few solid guidelines. Bankers are looking at the power contract, life of equipment, projection of long term demand for the product and the general business climate before making a decision on loan duration. They want to be sure they get their money back.

Projects with long duration evaluations increase the magnitude of the before and after tax affect of capital usage and the cost of power consumption. Your management wants to get a return on their investment, and that may be the deciding factor for evaluation. More will be discussed about this later.

Present worth calculation

*The **present worth** of a single or multiple future payments (known as cash flows) is the nominal amounts of money to change hands at some future date, discounted to account for the time value of money, and other factors such as investment risk. A given amount of money is always more valuable sooner than later since this enables one to take advantage of investment opportunities. Present values are therefore smaller than corresponding future values. (Wikipedia)*

Calculating the present worth of a stream of income or expenses is simple.

$$PW = C [1 - [1 + (r/100)]^{-n}] / (r/100)$$

PW = Present worth of a stream of payments or expenses.

r = annual interest rate in percent

C = Capital expenditure.

n = number of years

The choice of interest rate (r) can vary depending on the consideration for risk. It could be the prime rate, loan rate, corporate weighted average cost of capital, minimum return on capital, inflation rate plus a premium, or other risk adjusted value.

For example the *present worth factor* for \$1 for 20 years at 7% interest is:

$$PW = 1 [1 - [1.07]^{-20}] / (0.07) = 10.6$$

What is the cost of capital?

The first cost is not the only consideration. Many adjustments may be necessary. A few considerations are listed below:

Adjustments to Capital:

A **Minimum Return on Capital** is required if the project is to be successful. Usually this is set as the overall cost of corporate capital which might be from stock, bonds, or loans, and it is often a combination of the weighted average of all three.

Income Tax on Return of Capital for the purpose of evaluation of different investments is not the same as for the Internal Revenue Service. The only concern is for the tax on the capital with respect to the minimum acceptable rate of return. If you make more you will pay more, but that should not be part of the decision making process.

$$T = R / 1 - R (i + id - d') C'$$

T = Tax rate in % of Capital

R = Income tax rate in decimal format (0.40 +/-)

i = minimum acceptable rate of return on investment (0.075)

id = depreciation/amortization reserve in % (decimal equivalent) on sinking fund basis

d' = bank depreciation for IRS in % (say 3.3% straight line- decimal equivalent)

$$C' = 1 - (B * b / i) \quad [\text{taxable capital}]$$

B = Fraction of Capital related to bonds

b = interest on bond debt

Ad Valorem Taxes (Local or state property taxes) are generally based on an assessed value set as a percentage of the initial plant and equipment total capital cost (say \$20 per \$100 of total cost). Then the assessed value is taxed at a rate per \$100 of the “assessed value”. The

final result might be 1.5 to 2.5% of the initial total capital cost.

General and Administrative expenses might be a small percentage of the initial capital cost of a large power plant (maybe 1%) and a larger percentage of a smaller plant where the costs of salaries managers, legal services, advertising, etc. make up a larger percentage of the initial plant cost (maybe 2% or higher)

Insurance expenses are often 0.1% to 1% of the initial capital cost of the plant.

Depreciation and Amortization (or capital recovery) is the loss due to wear and tear, obsolescence, and other factors that cause the ultimate retirement of the equipment. The “minimum acceptable rate of return” is the return *on* investors’ capital, and “depreciation/amortization” is the return *of* investors’ capital. This does not need to be the same as the allowable tax rate of depreciation. Think of it as a sinking fund where the amount of a periodic payment increases to the value of the initial cost.

$$A = F [i/(1+i)^n - 1]$$

A = periodic payment

F = accumulated money

i = interest rate (%/100)

Percentage depreciation = A/capital cost

Cost of Capital Example

	% of Capital
Minimum Return on Capital	7.0
Income Tax on Return	2.5
Depreciation/Amortization Reserve	1.0
Ad Valorem Taxes	2.5
Administration General Expenses	1.0
Insurance	0.2
=====	
Total annual fixed charge	14.2%
Years of evaluation	20
Required return on capital	7%
Annual fixed charge	14.7%

Present worth factor for \$1 for 20 years at 7%

$$PW = 1 [1 - [1.07]^{-20}] / (0.07) = 10.6$$

$$Present Worth of Capital = (0.142)(10.6) * C = 1.50 C$$

Each dollar of capital expenditure today should be considered as \$1.50 because it requires having \$1.50 on hand today to pay off the equal annual obligation of \$0.142 fixed charges.

Therefore, the simple adjustment to the first cost of the product or component is to increase the price by the *Present Worth of Capital factor*.

What is the cost of energy?

National Average cents per kW-hr = 8.77

Hours per year = 8,000 (there are 8760 hours in a year, but there may be downtime for maintenance or lack of demand for the product)

Present worth Factor 20 years at 7% = 10.6

Present worth cost of power = $0.0877 * 8,000 * 10.6 = \$7,437/\text{kW}$
 $= 7,437 * 0.746 = \$5,548 / \text{horsepower}$

If power consumption is tax deductible (estimate 40% total rate State and Federal):

Power Cost = $5,548 * 0.6 = \$3,330 / \text{HP}$

What components should be evaluated?

The cooling tower fans are not the only source of power consumption. The pumping loop through the condenser interconnecting piping and the tower distribution system is often the most critical controlling factor. The fans may not run all the time, but at least one pump probably does. Especially on large projects with flow rates in excess of 30,000 GPM we find the pumping head controls the basic configuration of tower used, such as crossflow versus counterflow and film fill versus splash fill in many instances.

Part of the design process might include an investigation to see if it pays to use a taller fan stack. If there are no evaluation factors the only tool to use is an attempt to adjust the height to fully load a motor, and that may not be the correct decision. If evaluation factors are available the cost of the taller fan stack can be compared to the savings in fan power for getting a greater velocity recovery effect. The same can be true for investigating different fill heights, types of fill and drift eliminators, air inlet heights, and various tower configurations. For these reasons evaluation factors should be provided with the request for proposals.

Modifications for variations in operating modes, weather and heat loads

A review of the actual plant operation for an entire year might indicate that the cooling tower fans will not run at full speed everyday, all day. Winter heat loads for a building will be 30% of summer load while the heat load for a refinery might be the same all year. Cooling too much in the winter might causes problems for a steam turbine. A geothermal plant may be able to use the coldest water it can get all year around. It might pay to run a chiller with colder water down to the point just prior to sucking oil in order to reduce the compressor back pressure, but at that point it is necessary to start shutting down fans, number of cells, number of pumps and run fewer chillers. Each project should be reviewed to determine the possibility of variations for optimum usage. 33% or 50% pumping capacity will reduce the evaluated pump power, and using ½ speed or VFDs on the fans will reduce the evaluated fan power.

Another major consideration is the method of operation to be used. I know of some installations that are operating only in the afternoons on a hot summer day to keep the peaking load down and through this method they have great penalty costs for exceeding maximum allowable meter readings as allocated by the power companies. Maybe this is starting a diesel engine, a gas turbine or diverting steam from an operation, but in many cases it is a justifiable application.

For example fans running at half speed will use about 1/5 or 1/6 of the full speed power for half the hours of a year and the cost of fan power can be reduced accordingly. Using the overall power costs calculated above the actual fan power costs for the year can be further reduced:

$[(4,000 * \$3,330) + (4,000 * \$3,330 * 1/5)] / 8,000 = \$1,980 / \text{HP}$ weighted average fan power cost.

Some condenser and heat exchanger pumps are always running, even if the cooling tower fans are turned down for cold weather operation, and the pumping cost must certainly be considered a primary expense of operating the plant. There may be practical limits on turn-down of pumps in cold weather because the cooling tower nozzles may not provide adequate water distribution to prevent freezing in the fill, fouling of the fill or excessive drift due to mal-distribution of the air or water. Maybe only half of the cells or pumps run in the winter.

Pumping power (English Units) at 85% pump efficiency can be calculated as:

BHP/ft = 0.000297 * GPM (simplified 0.0003 * GPM)

BHP = brake horsepower

Ft = foot of pump head

GPM = flow rate in gallons per minute

Pumping Cost = 50,000 * 0.0003 * \$3,330 = \$49,950 / ft pump head

Chances are that the pumps run all the time and fans run 50% of the time. To simplify the presentation the example below uses this assumption. Remember, the object is not trying to evaluate the entire project: rather it is to make rational decisions regarding which cooling tower design options are best.

I don't know of any manufacturer who is really thrilled with the possibility of doing the full optimization study for you until you have gone through the preliminary steps. If you go far enough to give them some basic tools to work with they will generally make several selections to help you confirm your optimization. They just don't want to make a hundred selections when you are only going to choose one. At the time of requesting bids you should give the vendor guide lines: cost of fan power – cost per foot of pump head – concrete basin cost – demand cost for electrical connections and controls – cost of piping.

Although it is not the purpose of this paper to design the tower, the purchaser should realize that sometimes all of the power evaluation cannot be used. There are good practice design standards that should be considered. Some examples are: 1) high fan power evaluation leads to low fan discharge velocities with increased possibility of recirculation, 2) high pump head evaluation leads to low inlet height with high inlet air velocities to the extent air by-passes portions of the fill and the tower does not perform properly, 3) high fan and pump power costs lead to large tower plot areas with light water loadings that cause poor distribution with inadequate wetting of all of the fill surfaces, winter freezing problems, and poor nozzle distribution when one pump is shut off. It is recommended you review the design and your anticipated operating modes with your cooling tower consultant.

Analyzing the Bids

After the bids are received the first task should be to make sure each selection will perform as required. Equalize the bids for compliance with the specification and then compare power consumption. *Premature evaluation is not advised because adjustments to the design may be necessary to assure compliance with the technical specifications.*

The selections shown in the table below are examples of the variations that can exist. All selections were made for the same thermal duty of flow rate, hot water, cold water, and wet bulb temperatures. The exact conditions are not important for the purpose of this presentation. The object is to show the relative magnitude of costs of energy versus capital expenditure. If you budget too low on capital cost initially funding may not be adequate when you go to buy the equipment. If you budget too high it may kill the project before it gets started.

Pump heads shown are for the tower only, and they do not include piping losses or pressure drops of other equipment. For a more detailed analysis you may want to add in the cost of various numbers and sizes of risers and other piping, the cost of VFDs for one or more of the fans, 2-speed motors, wiring and control costs, etc.

Example	A	B	C	D
Tower Type	Counter flow	Counter flow	Counter flow	Counter flow
No Cells	4	3	4	4
W * L	42 * 42	48 * 48	42 * 48	48 * 48
Fan Diameter	32	32.8	32.8	32.8
Stack Height	10	18	14	10
Fill height	5	6	6	5
Inlet height	11	13	12	13
Pump head	23	26	25	24
BHP/Fan	169	223	116	99
First Cost	883,000	923,000	1,020,000	1,010,000
First Cost * 1.5	1,324,500	1,384,500	1,530,000	1,515,000
Fan Power @ \$1,980/HP	1,338,480	1,324,620	918,720	784,080
Pump Head @ \$49,950/ft	1,148,850	1,298,700	1,248,750	1,198,800
Conc. Cost * 1.5	286,583	271,458	324,083	356,458
Total Evaluated NPW	4,098,413	4,279,278	4,021,553	3,854,338

Evaluation factors are also helpful in considering various tower components. Please note that in the examples given above the fan stack height varies. The energy cost can be used to decide if the present worth savings in fan power due to better velocity recovery from a tall fan stack saves enough to offset the extra cost of the taller fan stack. Changes to motor and starter sizes can also be included. The number of cells may change the piping costs.

The ratio of the savings in operating costs and the additional fixed charges should be at least one to one if the client is to break even. Some clients, though, for business reasons may not value the present worth of future savings as much as current capital expenditures. If the capital is not available to start the project it will never get built. Maybe management will

apply an additional 1.2 factor on extra capital expenditures for this reason. Decisions like this can be justified if there is a possibility the equipment could be modified in the future. For example, maybe another cell could be added in the future to reduce plant cold water temperatures for increased production after the project has been proven profitable.

All of these economic studies will assist in making a selection regarding which type of product to purchase and what its power evaluation should be. However, ultimately the final decision must also include the reliability of the supplier, including reputation or expectation that the product will meet its thermal performance requirements and that the equipment will be suitable for the expected maintenance life of the components of the tower and the life of the tower itself. It is suggested that you condition each vendor's offering to assure that it will meet the design performance requirements before you buy, and that the people evaluating the bids have the expertise and database to tell the difference. After all of that, it is recommended that you test the final product to assure that you received what you asked for.

As you consider the concepts of this paper please keep in mind that it can be used just as easily to justify modifications to existing cooling towers as it can for evaluating new towers. Some Engineer/Constructors have been advising that their clients have been modifying their cooling towers in an effort to reduce energy consumption in order to do what they can to reduce their contribution to global warming.

The simplified concept of a *present worth of capital factor* along with the *present worth of fan power and pump power* is all you need to make an economic analysis of your cooling tower bids.

Acknowledgement:

1. Several concepts contained in this paper come from notes and private conversations with Millard Cherry and Paul Leung of Bechtel Corporation during the spring of 1974 in preparation for a presentation to the Pacific Energy Association in Los Angeles, CA.
2. Cost of energy in various USA locations can be obtained at:
www.eia.doe.gov/cneaf/electricity/epm/tables5_6_b.htm
3. Federal Corporation Taxes can be obtained at:
www.infoplease.com/ipa/A0005946.html
4. State Corporate Income Tax Rates can be obtained at:
www.taxadmin.org/fta/rate/corp_inc.html

About the author

Richard J. DesJardins is a Cooling Tower and Evaporative Cooling Consultant. He received his BSME from the University of Colorado in 1959 and MBA from the University of Missouri at Kansas City in 1965. Prior to formation of his own company in 1984 he worked for twenty-five years with the Marley Co and its subsidiaries. He has represented several different cooling tower, heat exchanger and industrial equipment manufacturers, been Principal Engineer for an air pollution control company, designed and fabricated several different types of evaporative cooling equipment, and consulted for many companies and cooling tower manufacturers. He is the author of cooling tower and psychrometric computer programs and Cooling Technology Institute papers TP92-01 and TP06-01.