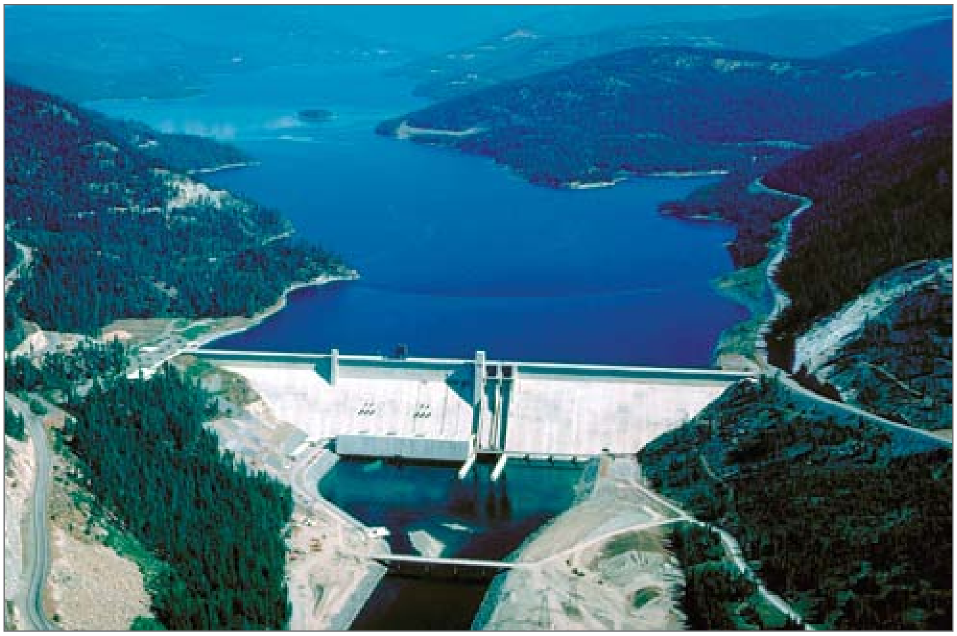

Population growth in the U.S. has fueled a 33% (since 1980) increase in demand for Public-Supply water.

Reducing Water Consumption in Compressed Air Systems

By Nitin G. Shanbhag, Senior Manager, Air Technology Group, Hitachi America

Compressed air systems are sometimes called the "4th Utility" due to their presence in almost all industrial processes and facilities. The objective of this paper is to focus on the opportunity to reduce the water consumption of compressed air systems. Water consumption has leveled off in the U.S. as reductions in the power, irrigation, and industrial segments have offset increases in the public-supply segment driven by population growth. Energy managers should understand how much cooling water is required for the inventory of air compressors in their factories along with the related costs. An evaluation can then be made, of the different types of cooling systems, to ascertain water and cost reduction strategies.

Section I: Offsetting the Increase in Public-Supply Water Use in the U.S.

Total water use in the United States in 2005 was estimated at 410 billion gallons per day by a 2009 study conducted by the U.S. Geological Survey[1]. This study, "Estimated Use of Water in the United States", has been conducted every five years since 1950. Data for 2010 water use will first become available in 2014.

The report indicates that national water use remained roughly the same as in 2000 and that water use has declined 5 percent from the peak in 1980. This leveling off of demand has occurred despite the population growth of 31 percent from 1980 to 2005 (230 to 301 million people)[2]. This population growth has led to a 33 percent increase in public supply water use over the same period. Fortunately, water use for thermoelectric power generation, irrigation, self-supplied industrial uses, and rural domestic/livestock have stabilized or decreased since 1980.

Power Generation and Irrigation Water Use Stabilizes

Thermoelectric power has been the category with the largest water withdrawals since 1965, and in 2005 made up 49 percent of total withdrawals[3]. Thermoelectric-power water withdrawals peaked in 1980 at 210 billion gallons of water per day and were measured in 2005 at 201 billion gallons per day. Partially due to sections of the Clean Water Act, that were amended in 1972, power plants have increasingly begun to use wet recirculating cooling systems (cooling towers or ponds) and/or dry recirculating cooling (air-cooled) systems instead of using once-through cooling systems. This has played a leading role in reducing demand for water in power plants.

Table 1: Total Water Use in the U.S.

Total Water Use in the U.S.	Billion gallons per day in 2005	% of Total	% Change 1980-2005
Thermoelectric Power	201	49%	-4%
Irrigation	128	31%	-15%
Public Supply	44	11%	+33%
Industrial	31	8%	-31%
Rural Domestic/ Livestock	6	1%	-7%
Total	**410**	**–**	**-5%**
Population	230 million in 1980	301 million in 2005	+31%

Source: 2009 Circular 1344, U.S. Geological Survey, "Estimated Use of Water in the United States in 2005".
Note: Data for 2010 water use will first become available in 2014.

Irrigation is the second largest category for water use and is also declining. Estimated water use in 2005 was 128 billion gallons of water per day – down 15 percent from the peak in 1980 and representing 31 percent of total use.

- The average application rate for irrigation water has declined steadily from 3.55 acre-feet per acre in 1950 to 2.35 acre-feet per acre in 2005.
- This decline is attributed to greater use of more efficient sprinkler systems rather than flood systems[4].

Table 2: Trends in Total Water Withdrawals by Water-Use Category (U.S. Geological Survey)

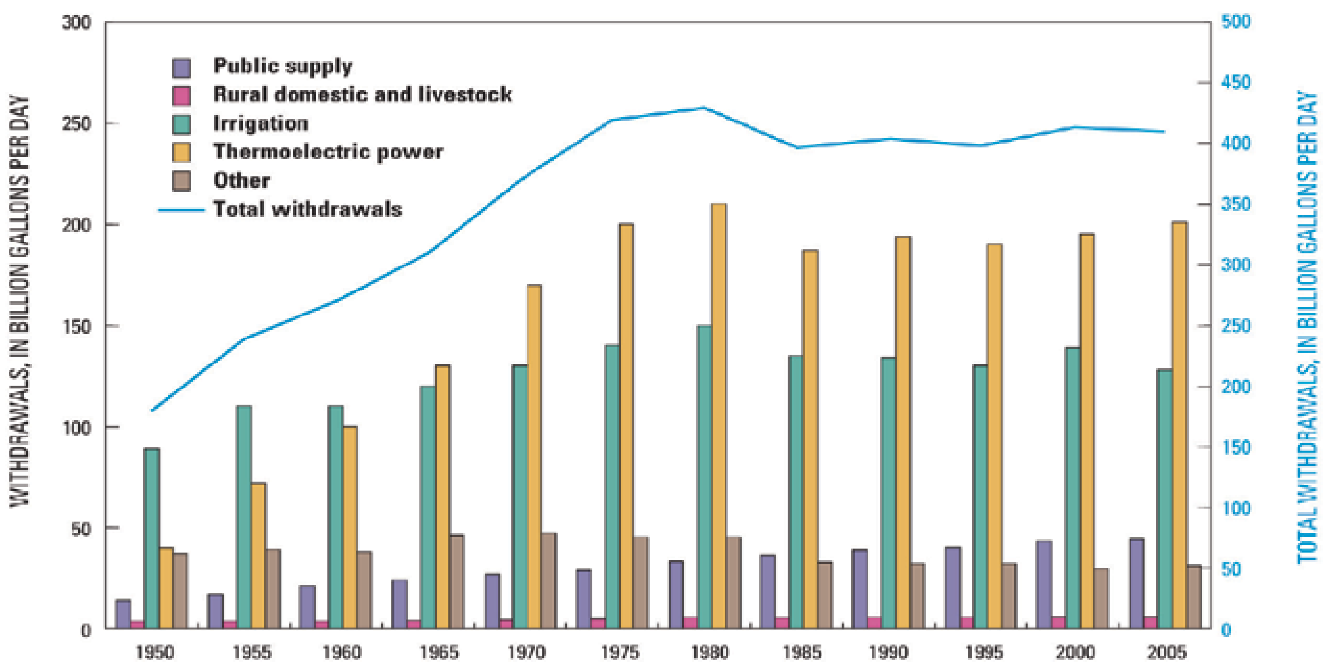


Figure 14. Trends in total water withdrawals by water-use category, 1950–2005.

Source: 2009 Circular 1344, U.S. Geological Survey, "Estimated Use of Water in the United States in 2005". Note: Data for 2010 water use will first become available in 2014.

Public Supply Water Use Increases

Public supply refers to domestic, commercial, and industrial users of public water supply systems. Public supply water use was 44.2 billion gallons of water per day in 2005 – up 33 percent from 1980. This is a reflection of the population increase over the same period of 31 percent.

- Domestic use made up 58 percent of the total while commercial/industrial made up 42 percent.
- The commercial/industrial number is a catch-all including industrial facilities, wastewater treatment plants, firefighting, pools, parks, system losses, and all buildings with more than 15 connections[5].

Self-Supplied Industrial Water Use Decreases

Industrial water use includes water used for such purposes as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product, or for sanitation needs within the manufacturing facility. Some industries that use large amounts of water produce such commodities

Table 3: Trends in Population and Freshwater Use by Source (U.S. Geological Survey)

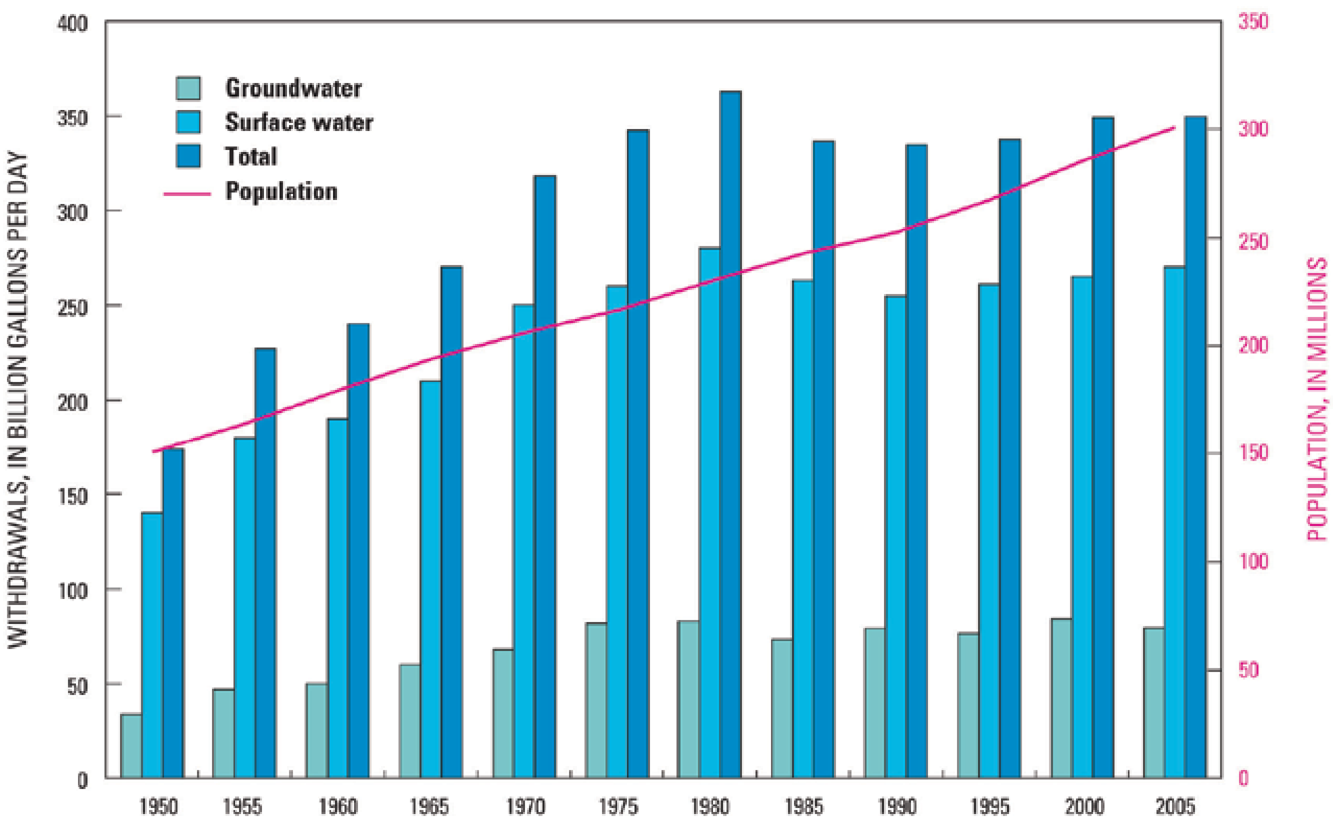


Figure 13. Trends in population and freshwater withdrawals by source, 1950–2005.

Source: 2009 Circular 1344, U.S. Geological Survey, "Estimated Use of Water in the United States in 2005". Note: Data for 2010 water use will first become available in 2014.

as food, paper, chemicals, refined petroleum, or primary metals. Water for industrial use may be delivered from a public supplier or be self-supplied. Stricter water-quality standards for water discharges, mandated by the Clean Water Act, may have also encouraged water conservation. The data taken from this U.S. Geological Survey looks at self-supplied industrial water[6].

- Self-supplied industrial water use was 31 billion gallons of water per day, a decrease of 31 percent from 2005 to 1980[7].
- Significant growth in water use has been seen in the "Aquaculture" industry – the farming of fish.
- The use of water in the mining industry remained relatively flat.
- This reflects a decrease in manufacturing employment of almost 19 percent from 1990-2005.
- Employment in several major water-using industries showed even larger declines:
  - Primary metal manufacturing declined 31 percent.
  - Paper manufacturing and petroleum industries declined 26 percent.
  - Employment in the chemical manufacturing industry declined 12 percent.

Section II: Water Consumption in Industrial Compressed Air Systems

Compressed air systems are present in almost all industrial processes and facilities. They have been correctly identified as an area of opportunity to reduce electrical (kW) energy costs through measures like reducing compressed air leaks and identifying artificial demand and inappropriate uses. Water-cooled air compressors can also be significant consumers of water and reducing these costs can represent a second area of opportunity.

A very "typical" industrial plant running two 125 horsepower, water-cooled, single-stage, rotary screw,

Table 4: Cooling Water Requirements for Single-Stage Rotary Screw Air Compressors

Typical Lubricant-cooled Rotary Screw Cooling Estimated Heat Rejection to Cooling Water (btu/hr)*				Typical Values for Air-Cooled Oil-Coolers Estimated Heat Rejection to Cooling Air (btu/hr)*		
Air Compressor Capacity CFM/HP**	Water-cooled Oil-Cooler and After-Cooler btu/hr	Approx. gpm at 70 ˚F	Approx. gpm at 85 ˚F	Air Compressor Capacity CFM/HP*	Air-cooled Oil-Cooler and After-Cooler btu/hr	Approx. cfm Cooling Air
250/62	150,900	6	10	250/62	156,300	8400
350/83	200,300	7	12	350/83	208,500	8400
500/120	276,700	11	18	500/120	287,700	12000
800/215	445,500	16	27	800/215	463,100	17500
1000/250	550,400	23	39	1000/250	572,400	28700
1200/300	668,200	33	56	1200/300	694,700	28700
1500/350	889,709	33	56	1500/350	920,000	36000
2500/500	1,543,000	49	79	2500/500	1,543,000	45000

* This data is general in nature and should not be used to select equipment. It is necessary to look at the specific engineering data for all equipment being used.
**System at 100 psig

air compressors can consume 11.4 million gallons of water per year. A larger installation, with a 350 horsepower rotary screw under similar circumstances, can consume 17 million gallons per year[8].

Many older facilities continue to use two-stage, water-cooled, reciprocating air compressors. Pulp and paper mills and steel mills are perfect examples. Facilities, like these, can require 550 million gallons per year of cooling water for the air compressors.

Both air compressors and compressed air dryers can be water-cooled. We highly recommend that energy managers, at multi-factory corporations, take an inventory of the water-consumption of all the installed air compressors and of how the water-cooling systems function. An evaluation should be made, in each facility, of the feasibility and benefits of switching to an air-cooled air compressor or switching to a different water-cooling system.

How Much Cooling Water is Required by Air Compressors?

The standard rating, for air compressor cooling water requirements, is how many gallons of water per 1,000 btu/hr is rejected into the cooling water flow. Air compressors generate a high rejection load due to their very basic inefficiency – i.e. it takes 7 to 8 input horsepower to supply 1 hp of work

Table 5: Cooling Water Requirements for Two-Stage Reciprocating Air Compressors

Two-Stage Reciprocating Air Compressor Cooling Water*						
			Inlet Air 60 ˚F, Water 75 ˚F		Inlet Air 100 ˚F, Water 95 ˚F	
Bhp Class	Discharge pressure psig	Cap acfm	Air discharge ˚F	gpm water required	Air discharge ˚F	gpm water required
150	125	772	335	16	370	16
200	125	1050	335	21	370	21
250	125	1300	335	26	370	26
300	125	1560	335	32	370	32
350	125	1840	335	37	370	37
400	125	2035	335	41	370	41
450	125	2340	335	52	370	52

*This data is general in nature and should not be used to select equipment. It is necessary to look at the specific engineering data for all equipment being used.

The Clean Water Act

The Federal Water Pollution Control Act of 1948 was the first major U.S. law to address water pollution. Growing public awareness and concern for controlling water pollution led to sweeping amendments in 1972. As amended in 1977, the law became commonly known as the Clean Water Act (CWA). The 1977 amendments:

- Established the basic structure for regulating pollutant discharges into the waters of the United States.
- Gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry.
- Maintained existing requirements to set water quality standards for all contaminants in surface waters.
- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.
- Funded the construction of sewage treatment plants under the construction grants program.
- Recognized the need for planning to address the critical problems posed by nonpoint source pollution.

Source: United States Environmental Protection Agency (EPA), http://www.epa.gov/lawsregs/laws/cwahistory.html

A modern air-cooled, oil-free, rotary screw air compressor

in compressed air. This creates a heat-of-compression generated during the process reflecting this inefficiency. Energy input not converted to work shows up as heat. This heat has to be removed for the equipment to run and for the plant to be able to use the air. Particularly today, where dry compressed air is often critical, it must be reliably and effectively after-cooled and dried to a specified pressure dew point using compressed air dryers.

Calculating the required gallons-per-minute (gpm) is dependent upon several critical variables:

- Intake cooling water temperature to the air compressor or dryer.
- The allowable compressor discharge temperature – i.e. reciprocating, oil-free rotary screw and centrifugals easily handle 350 to 400 ˚F discharge. Lubricant-cooled units are limited by the cooling lubricant fluid but are usually a maximum of about 200 ˚F.
- Other critical data is needed such as OEM rated air flow (acfm at full load pressure), compressor shaft power (BHP), and motor input HP/KW inclusive of motor/drive losses.
- GPM is typically provided, relative to cooling water requirements, by the manufacturers of air compressors.

Three Primary Sources of Industrial Cooling Water

Public Supply Water

Discussed in the U.S. Geological Survey as the category that continues to grow in water use. Over the last 40 years these costs have escalated rapidly reflecting the scarcity of water and the cost of water treatment. It is becoming the exception to the rule today to see a compressed air system's cooling-water supply coming from the municipal utility. True costs are not always evident. Additional costs, like sewer chargers, can't be ignored. Often, city water will still require water treatment for effective performance in industrial cooling. These costs must also be considered.

Self-Supplied Well-Water

Well-water has varying site-specific characteristics but it is generally not "Free". After the well is drilled, in most parts of the world the good news is that the water is usually cool. The bad news is that it usually requires significant intake filtration and water treatment for industrial use. Electric energy is required to pump it out of the ground and through the equipment. Today, the cost of disposing of the heated cooling water has escalated as various agencies may limit the dumping of the heated water into streams, rivers and lakes due to potential thermal pollution. This is what has driven the thermoelectric power plants to alternative cooling systems. In many areas well-water supply is diminishing as the water tables are lowering and as the well gets older, the total flow in gallons-per-minute (gpm) falls off.

River Water/Lake Water

River and lake water have the same limitations as well-water with regards to intake filtration and water treatment. In many, if not most, areas today it is no longer "free" and there often is a charge for the discharge-heated water to the local body of water. There are also EPA Clean Water Act regulations to be met and monitored with any water being discharged to this type of water supply.

Calculating the Basic Water Costs for Compressed Air Systems

Regardless of what "rule of thumb" number is used for water cost (not including energy use) it will probably not be right for each particular location. This cost is very site specific and should be the first factor identified when embarking on a water cost, energy-control program. All of these escalating costs, along with the man hours required to measure and manage the process, have created a great incentive for industrial plants

"Rule of Thumb" Formula to Calculate Water-Cooling Costs of Air Compressors

(a or b) + c

Formulas:

a. Untreated Cooling Water Cost = (Gallons per year/1000) x $3.00

b. Treated Cooling Water Cost = (Gallons per year/1000) x $4.20

c. Compressor Enclosure Vent Fan Electric Cost = (Input kW x hours x ($/kWh)

Example:

A water-cooled, two-stage, rotary screw, lubricant-cooled, 100 horsepower air compressor. Assumptions:

- 8600 working hours per year (to take into account down-time)
- Cooling water use volume of 11 GPM at 70 °F
- Untreated Cooling Water Cost of $3.00 per thousand gallons
- Compressor Enclosure Vent Fan Input Power of 1.1 kW
- Electrical energy cost of $0.06 per kWh

Solution:

- Step 1 to Calculate **a**: 8600 hours x (11 GPM x 60) = 5,676,000 gallons of water per year
- Step 2 to Calculate **a**: (5,676,000/1000) x $3.00 = $17,028.00 untreated cooling water cost per year
- Step 3 to Calculate **b**: 1.1 kW x 8600 hours x $0.06 kWh = $567.60 vent fan electric cost per year
- Step 4: $567.60 + $17,028.00 = $17,596.60 total annual cooling costs

to supply or replace all their own plant water utility.

The net result of these cost factors for cooling water have resulted with most design engineers using a "default cost" of **$3.00 (USD) per 1,000 gallons** of cooling water – when the actual site situation is unknown. The accompanying water treatment cost is about specific situations and can be much higher depending on site conditions and maintenance diligence – $1.20 per 1,000 gallons based on 40 grains of hardness, alkalinity 10, and biocide treatment included.

A modern air-cooled, oil-free, rotary screw air compressor

Switching to Air-Cooled Air Compressors

In light of escalating water costs and regulations, plants have sought

Table 6: Comparing Costs of Water- and Air-Cooled Systems: Two-stage, Lubricant Cooled, 100 hp, Rotary Screw Air Compressor

Comparing Cooling Requirements Lubricant-Cooled, Two-Stage, Rotary Screw Compressor	Two-stage Lubricant-Cooled 100 hp Class 547 acfm /111 bhp at 100 psig Discharge 180–200 ˚F	
	Water	Air
Gpm at 50 ˚F Electric $.06 kWh at 8,600 hours/yr.	8	5.5 fan hp/ 5kW/$2,580 yr.
Gpm at 70 ˚F	11	N/A
Gpm at 80 ˚F	18	N/A
Total H_2O pressure loss (psid)	21	N/A
Vent fan Input Power	1.1 kW	N/A
Cooling Cost at 70 ˚F H_2O (H_2O costs at 3.00 per 1,000 gallons)	$17,028 per year	–
Vent fan cost	$568 per year	N/A
Water & Electrical Energy Cost at $.06 kWh/8600 hrs/yr.	$17,596 per year	$2,580 per year
Total Heat Remaining	303,000 btu/hr	

to decrease their cooling water requirements. Compressed air systems have become prime targets for continuous duty air-cooled air compressors. Some air-cooled rotary screw compressors have seen design improvements and can accept higher ambient temperatures than in the past.

The benefits of switching are readily apparent in terms of reduced water consumption and costs. Using the prior example, an air-cooled, two-stage, rotary screw, lubricant-cooled, 100 horsepower air compressor will have 85% lower water and electrical energy costs – compared to a similar water-cooled unit. The air-cooled unit will simply deploy a 5 kW fan creating an energy cost of $2,850.00 per year. Assuming 8600 working hours per year to take into account down-time, the water-cooled unit, with cooling water at 70 °F, will use 5,676,000 gallons per year at a cost of $17,028.00 per year. Add the small compressor enclosure vent fan and the total annual cost is $17,597.00.

Using a similar example, an air-cooled, 200 horsepower oil-free, air compressor will see 89% lower water and electrical energy costs – compared to a similar water-cooled unit. The air-cooled unit will simply deploy a 10 kW fan creating an energy cost of $5,160.00 per year. Assuming 8600 working hours per year to take into account down-time, the water-cooled unit, with cooling water at 70 °F, will use 7,236,600 gallons of water per year at a cost of $44,892.00 per year. Add a small compressor enclosure vent fan and the total annual cost is $45,279.00.

Table 7: Comparing Costs of Water- and Air-Cooled Systems: Two-stage, Oil-free, 200 hp, Rotary Screw Air Compressor

Comparing Cooling Requirement Oil-Free, Two-Stage Rotary Screw Compressor	Two-stage Oil-free	
	200 hp Class	
	856 acfm/193 bhp at 100 psig Discharge 350–400 ˚F	
	Water	Air
Gpm at 50 ˚F Electric $.06 kWh at 8,600 hours/yr.	22	11 fan hp/10 kW/ $5,160 yr.
Gpm at 70 ˚F	29	N/A
Gpm at 80 ˚F	48	N/A
Total H_2O pressure loss (psid)		N/A
Vent fan HP	1/.75 kW/ 3,500 cfm	
Cooling Cost at 70 ˚F H_2O/$/yr. ($H_2O$ costs at 3.00 per 1,000 gallons)	$44,892	
Vent fan cost	$387	N/A
Water & Electrical Energy Cost at $.06 kWh/8600 hrs/yr.	$45,279	$5,160
Total Heat Remaining	599,000 btu/hr	

Both of these examples used conservative water temperatures of 70 °F, did not add the potential cost of $1.20 per thousand gallons for water treatment, and did not add pumping circulation costs.

When evaluating a switch to an air-cooled air compressor, however, particularly on units larger than 100 horsepower, it is important to seriously evaluate all the application variables like room ventilation, ambient temperatures, after-cooler and dryer performance capabilities, maintenance personnel and processes.

All this considered, looking at the differences, it is obvious why plants are looking for air-cooled units whenever possible and/or looking at how to minimize water cooling costs when air is not viable.

Section III: Six Different Types of Cooling Systems

Most air compressors are designed to receive cooling water, at the required flow, with a maximum inlet temperature of 100 ˚F and expect maximum discharge water temperatures of 120 ˚F to 130 ˚F. These values should be kept in mind when evaluating any compressor cooling system.

Evaluation of the cooling system for the compressor should include the after-cooler performance as it relates to the inlet temperatures it will provide to the compressed air dryer. Compressed air dryers are almost all designed to receive inlet air to be dried at 100 psig and 100 ˚F. With temperatures to the dryer above 100 ˚F (the rated inlet temperature), the moisture load per scfm to the dryer will increase significantly reducing the flow rating drying capability. For proper application, be aware of the inlet air temperature to the dryer and the design approach temperature to the incoming cooling media temperature – air or water.

With the exception of large water-cooled reciprocating compressors, most rotaries and centrifugal air compressors have relatively high pressure losses through them when compared to many others commonly fluid- cooled industrial pieces of equipment. Whenever possible, each compressor (or group of compressors) should be on their own system to avoid other pressure losses affecting the flow to the air compressors.

An effective trim cooler should be well controlled to effectively modulate the flow and manage the power use. Often these trim coolers are sized to be able to handle 100% of the load and keep the equipment running in the case of an emergency.

The energy use of the circulation pumps is a function of the flow volume and the head. Poor fluid piping, sizing and configuration can add pressure loss and head. Installing the cooler farther away from the compressors or on the building roof will also usually increase the cooling fluid "head" and require larger pumps.

Cooling System #1: Recirculation Ponds

Recirculation cooling water ponds are an option for a locally controlled cooling water system supply. As long as the pond is large enough to handle the heat load under the worst condition and maintain an acceptable temperature, it can be very effective, particularly in large installations. They do have some inherent limitations:

- Significant water loss due to ambient evaporation
- Continued buildup of silt in the pond may significantly reduce heat absorption capability and not remain usable
- Water treatment is still necessary
- Makeup water is usually with some kind of expense – i.e. well pump, etc.
- A pumping station is still required to circulate the cooling water

Cooling System #2: Trim Coolers

A trim cooler is a smaller heat exchanger to be used only in times of excess or peak heat loads. They are installed to complement a larger system designed to handle all cooling need 85-90% of the time. A trim cooler can allow a facility to go with a lower water consumption system by being there as an emergency back-up during high heat load periods. A trim cooler might be a shell and tube heat exchanger or a cabinet-enclosed chiller.

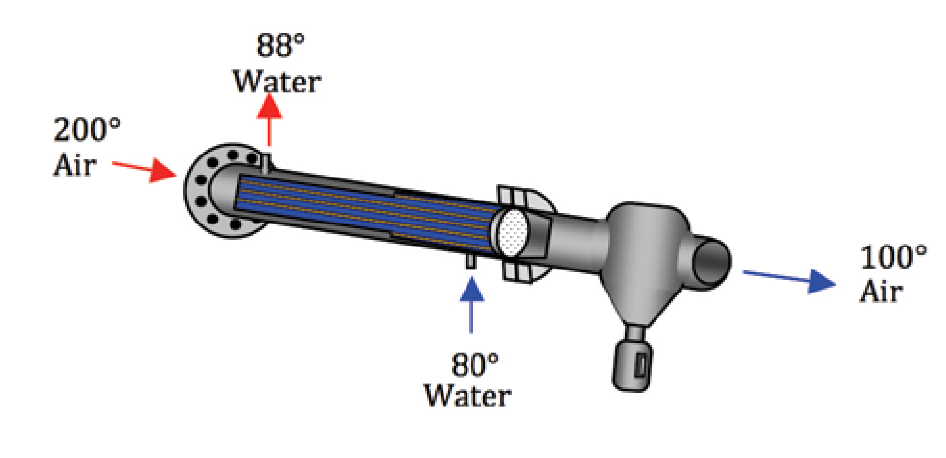


Figure: A water-to-air trim cooler

Cooling System #3: Dry Air Cooling – No Water Required

These coolers are closed loop cooling systems usually using an appropriate water (60%) and polyglycol (40%) mix (one-time fill) passing through finned tubes. The coolers are in modules – each with a small fan for air-cooling. As the heat load is reduced, the fans are shut-off individually as required and brought back on when needed. Dry air cooling systems are usually available from 160,000 btu/year rating at 250 cfm class to 4,000,000 btu/hr rating at 6,000 cfm class – with special sizes for other levels.

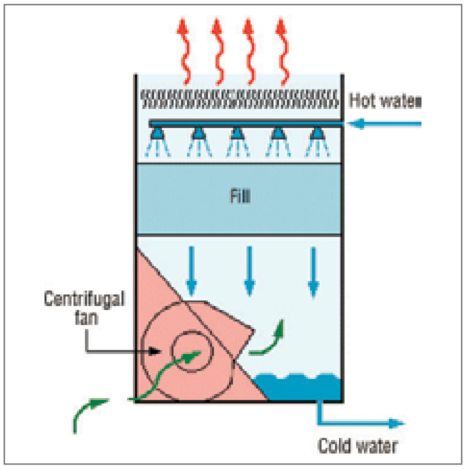
Typical Dry-Air Fluid Cooling System – Usually uses an appropriate water/glycol mix

The air-cooled heat exchangers can be manufactured to deliver a 2 ˚F approach temperature but economics usually dictate a 5 ˚F approach. This means in parts of the country they may be able to handle a reciprocating compressor's cooling needs with little or no trim cooling. Dry air cooling systems, when combined with a trim cooler, can provide factories with a very low-cost and reliable alternative to water-cooled machines.

Cooling System #4: Open Evaporative Cooling Tower

The cooling water system requiring the lowest capital costs is the open tower type. In this system, the heated return water flows down a controlled open path where it is cooled by continual evaporation by moving ambient air from a fan and pulling an evaporating water percentage into the ambient air. These towers will have a smaller circulating pump to move the water through the cooling area and a large horsepower electric motor fan to move ambient air over and through the cooling water to optimize the evaporation cooling. There is also a flushing or blow out system using water.

The primary benefit of this type of system is that as the ambient temperatures increase, generally so does the evaporation rate which means, in most North American locations, they will deliver about 85 ˚F temperature cooling water when operating properly within their design limits.



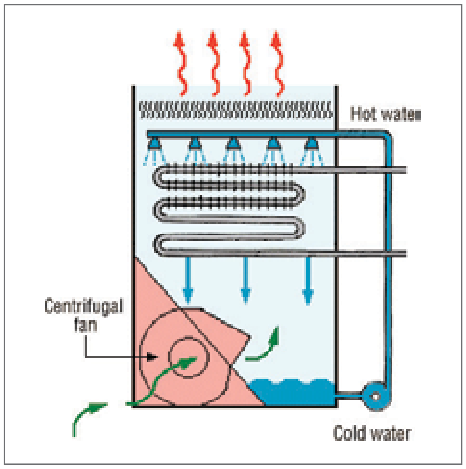
Typical Evaporation Open Tower with Counter Flow

Open tower coolers are very prevalent throughout industry and are often known affectionately as very effective "air washers" meaning they remove the dirt and impurities from the ambient air, generating a continual cleaning of the tower.

The contamination factor, along with the high level of make-up water required, makes proper and diligent water treatment and condition monitoring a prerequisite for a successful installation. Open towers also inject oxygen into the process water system which may or may not create corrosion or other maintenance issues.

Cooling System #5: Closed Circuit Cooling Tower with an Auxiliary Evaporation Cooling Assist for Hot Weather

In this type system the primary coolant is sealed in a closed loop system – unexposed to ambient air, it may be water – but it more often is a glycol water mix appropriate to the local ambient cold temperature



Typical Closed Circuit Cooling Fluid Tower with Evaporator

Table 8: Direct Cooling Water/Fluid Comparison of a 600 hp, 3-Stage Centrifugal Compressor, 2,750 scfm at 100 psig at 290 bhp

Compressor Cooling		1,000 btu/hr	gpm
After-cooler	1,000 btu/hr	1,547	—
	Gpm at 85 ˚F	—	124
Oil-cooler	1,000 btu/hr	145	—
	Gpm at 85 ˚F	—	29
Total	1,000 btu/hr/gpm	1,692	153

	Once – through Municipal Water	Open Evaporative Water	Closed Loop Evaporative Tower	Dry Cooler with Trim
Water cooled for compressor cooling – gpm/$yr.	153 $236,844	Recirculated	Recirculated	N/A
Total gallon/year at $3.00/1,000 gallons	78,948,000	N/A	N/A	N/A
Spray circulation pump motor at $.06 kW/8,600 hrs/yr.	N/A	kW/100% $516	kW/30% $155	
Main cooling system fan driver motor kW/yr. at $.06/8,600 hrs/yr.	N/A	75 hp 60 kW $30,960/yr.	11 hp 10 kW $5,160/yr.	(12) 1.5 hp 18 hp at 50% use 9 kW $4,644/yr.
Evaporative make up water – gpm $/year gallons/year	N/A	3.4 gpm $5,264/yr. 1,754,400	1.2 gpm $1,858/yr. 619,200	N/A
Flushing blow out water – gpm ($3.00/1,000 gallons) $/year gallons/year	N/A	45.9 $71,052/yr. 23,684,400	1.7 $2,632/yr. 877,200	N/A
Total Gallons of Water for Water Treatment	78,948,000	25,438,400	1,496,400	N/A
Water treatment costs at 42 grains hardness, 10 alkalinity, with biocide treatment at $1.20 per 1,000 gallons	$94,737	$30,526	$1,795	N/A
Trim cooler costs to operate during extreme hot weather; chiller cooler kW/% time at $.06 kWh/8,600 hrs/yr.	N/A	N/A	N/A	30% utilization 9 kW $1,393/yr.
Pump station electric motor kW – based on 160 gpm, 100 ft of head specific gravity 1.0 100% of time at $.06 kWh/8,600 hrs/yr.	7 kW $3,612	7 kW $3,612	7 kW $3,612	7 kW $3,612
Total Operating Cost Water $/yr.	$335,039/yr.	$136,666/yr.	$13,350/yr.	$9,649/yr.

limitations. This is very good for the equipment being cooled since it runs for a significantly long time without significant water treatment requirement or replenishment.

The cooling system is equipped with a motor driven spray pump and spray header which delivers a spray over the air cooled heat exchangers during hot weather and creates evaporation auxiliary cooling similar to the open tower described earlier.

Cooling System #6: Closed Loop Cooling with Evaporation

Closed Loop Cooling with Evaporation systems experience additional water use, the magnitude very much dictated by the ambient conditions. There is also a motor driven coolant circulation pump and motor drive main cooling air fan similar to the open tower. The standard pumping station is also required. Some flushing or blow may also be required.

Depending on design and operating conditions, this type of cooling towers use parallel flow or cross flow or counter flow. Compared to an open tower with evaporative cooling, the closed circuit cooling system has a higher initial cost but also some advantages which may be significant when the operating conditions dictate.

In a compressed air system the process water must be capable of full capacity throughout the year. This means maintaining a clean, reliable cooling fluid loop is critical. To do this in an open tower requires proper and diligent water treatment and maintenance. The closed loop system is basically isolating the compressor cooling fluid from all air ambient out borne contaminants:

- This reduces the frequency of the need to shut down the cooling system for cleaning.
- This type cooler has a lower volume of recirculating water requiring water treatment filtration
- The compressor cooling fluid usually requires minimal treatment
- During periods of dry operation (cooler weather) the need for spray evaporation and therefore makeup water is eliminated
- These units, like many central cooling water systems, are set up with either another cooling water source or chiller cooler. These trim coolers cool the fluid from the primary cooler when required by too high a temperature.

Conclusion

As the population continues to grow in the United States, industrial use will need to continue to fall to help offset the increases in Public-Supply water use. Compressed air systems provide an opportunity for energy managers to reduce associated cooling water consumption and costs. Understanding the costs and the alternative types of cooling systems is an important first step.

All options are preferable to "once through" municipal water. The ever-growing regulations and controls will just further increase these costs. The true cost of the open evaporative tower and the closed loop evaporative tower can be driven much higher with more significant water treatment cost, water disposal regulations, sewer costs and surcharges. If a facility can't simply convert a water-cooled air compressor to an air-cooled air unit, a dryer-cooler system (with trim) has the lowest costs and very predictable results.

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Endnotes

1 Estimated Use of Water in the United States in 2005, Joan F. Kenny, Nancy L. Barber, Susan S. Hutson, Kristin S. Linsey, John K. Lovelace, and Molly A. Maupin, U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia, 2009, Circular 1344, page
2 Ibid, Table 14, Trends in estimated water use in the U.S. page 43
3 Ibid, page 42
4 Ibid, page 45
5 Ibid, page 16
6 Ibid, page 32
7 Ibid, page 1
8 Figures taken from a data sheet of a single stage, lubricant cooled, rotary screw air compressors at 100 psig pressure, 8600 working hours, and 70 °F water temperature.

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