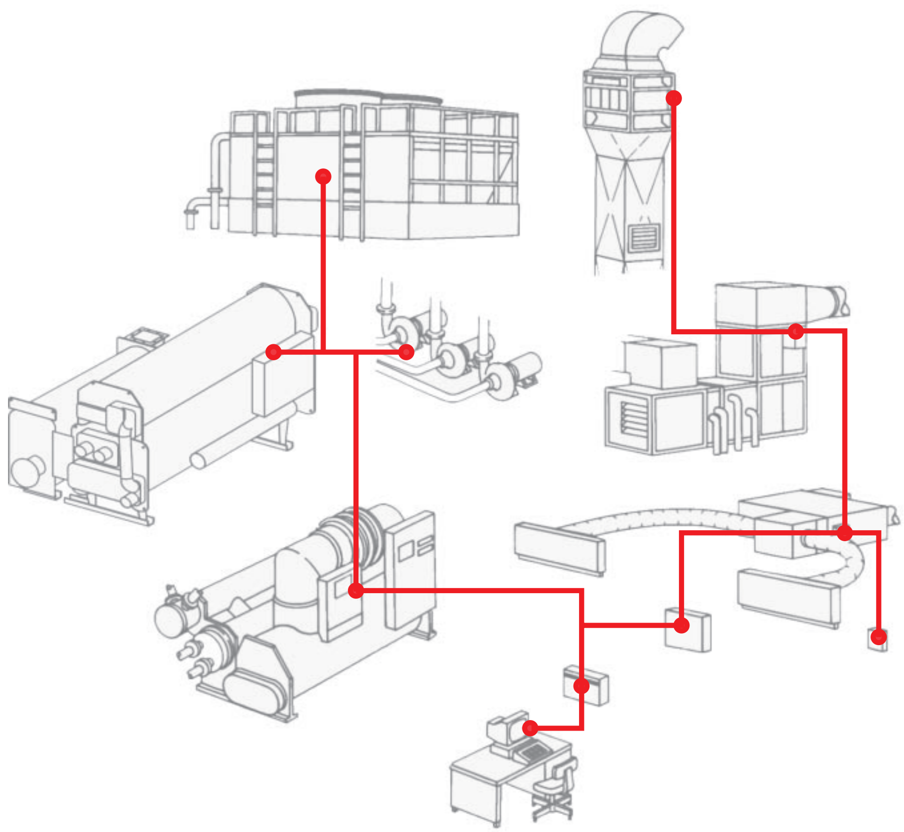
Chilled Water System Design and Operation

Cost-Reducing Optimization Strategies



Introduction

As a result of many different political and economic pressures, there is a worldwide effort to drive energy efficiency to the highest possible level. There has been a significant effort within the HVAC industry to improve efficiency of both existing and new systems. Equipment manufacturers and system designers both aim to produce quality, reliable, and highly efficient HVAC equipment and systems for the end user. Water chillers, used in many HVAC and process applications, are today a wonderful example of the drive to increase energy efficiency to the highest possible level.

Chillers Are Just One Part of the System

Traditionally, the performance of the chilled water system focused on the chiller because the chiller was the most significant energy consumer in the facility. Manufacturers of chillers have made and continue to make great progress to improve chiller efficiency. In the case of centrifugal water chillers, performance has improved from 0.75 kW/ton in the 1970s to less than 0.50 kW/ton today. This significant improvement in chiller performance has led many designers and facility managers to immediately reduce operating costs by replacing old and inefficient chillers.

Utilizing a high performance chiller can both reduce the energy used and alter the make-up of the chilled water system's energy usage. Ancillary equipment, such as water pumps and cooling towers, will make up a larger percentage of the chilled water system's energy usage. This can be seen in both Figure 1 below and Figure 2 on the next page. Many more opportunities for reducing overall energy use can be found by closer examination of the interaction between ancillary equipment and the chiller. Several will be highlighted in the following sections.

System Optimization Strategies Reduce Costs

Evaluating the interaction of components and maximizing the performance of the whole system is called system optimization. Amazingly, system optimization provides the ability to simultaneously increase the energy efficiency and reduce the capital cost of equipment and infrastructure. The key is to understand the interaction between the chiller, the water pumps, the cooling tower and the coils and then determine ways to exploit the strengths of each component to provide TRUE system optimization.

Three areas of system optimization will be examined:

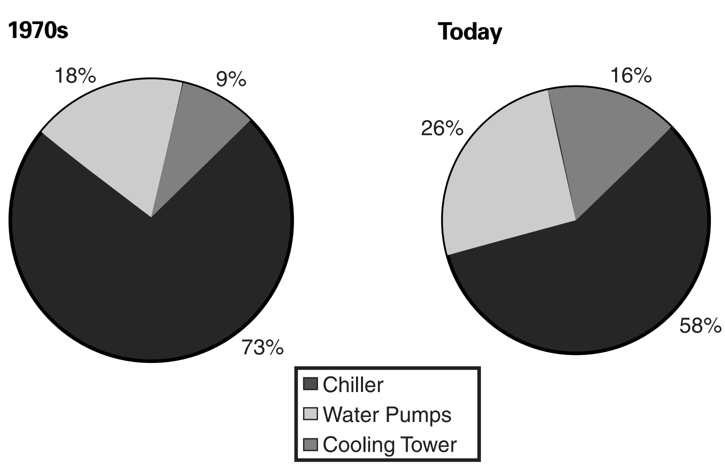
1) Condenser water flow rate and sizing the system components on the condenser water loop.

2) Chilled water flow rate, temperature and sizing system components on the chilled water loop.

3) Cooling tower water temperature control – minimizing energy consumption of the chiller and cooling tower.

Energy and capital cost reducing opportunities will be summarized for each optimization strategy.

Figure 1



Strategy #1: Reduce Condenser Design Flow Rates

The first system optimization strategy involves the designer's choice of condenser (or cooling tower) water flow rate. Energy savings are found by optimizing the design condenser flow rate based on the pump, piping, cooling tower and chiller energy usage at different flow rates.

Condenser (or cooling tower) water flow rate is usually kept relatively constant to assure proper cooling tower operation. In cooling tower operation, the capacity of the cooling tower is varied by the temperature water it produces. (Strategy #3 discusses cooling tower water temperature.) With constant condenser water flow, the pump(s) will consume the same power regardless of cooling load. Cooling tower fans also may operate continuously at a constant speed.

The figure below compares the chiller and ancillary equipment energy use as a function of load. As cooling load decreases, the water pumps and cooling tower fans become a growing percentage of the total energy consumption. By reducing this water pump and cooling tower fan energy consumption, there can be a significant reduction in the total energy usage of the chilled water system.

Water pump and cooling tower fan power requirements can be reduced by lowering the condenser (or cooling tower) water flow rates. Designing systems with less condenser water flow means that the water pumps and cooling tower fans can be made smaller. Smaller equipment is less expensive and requires less energy.

Reduction in construction cost can be accomplished by reducing the size of the condenser water piping. This will provide dramatic savings for designs with long pipe runs. For district cooling and central campus systems, reducing the pipe size may have a tremendous impact on the project construction cost.

Can lower flow rates really make a significant impact on energy use? Yes. Pump energy consumption is reduced by the cube of the reduction in flow. For example, when the pump is distributing 80 percent of the design water flow, the amount of energy consumed by the pump is now only 51.2 = $(80 \text{ percent})^3$ percent of the energy use. Note the energy consumption change of the pump in Figure 3. It significantly and consistently decreases with decreasing flow rate.

Figure 2 – Equipment Energy Use by Percentage of System

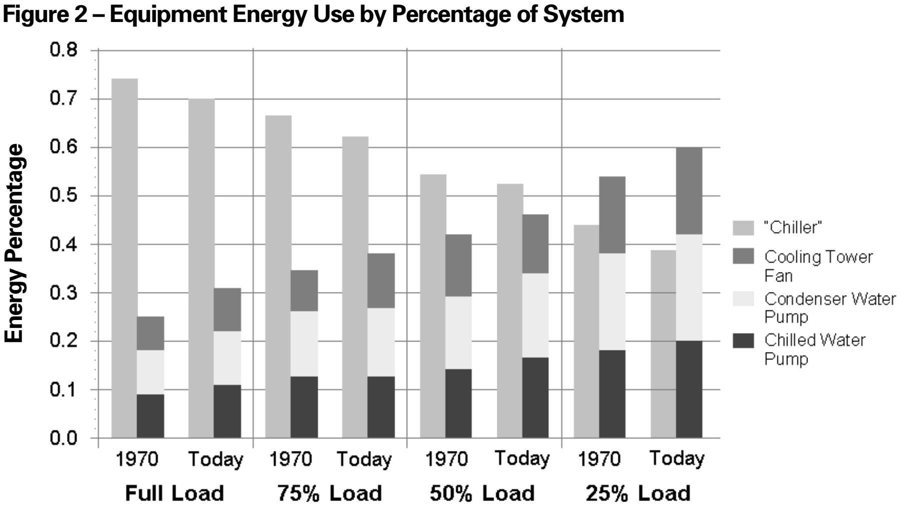
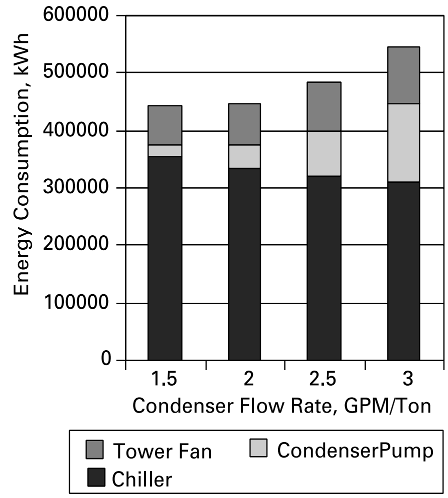


Figure 3 – Chiller Plant Energy Comparison



Summary of Cost Reductions

For New Construction:

1. Use smaller water pump size with a lower horsepower requirement to save energy and capital.
2. Use smaller cooling tower size with a lower fan horsepower requirement to save energy and capital.
   - Less real estate required
   - Reduced structural requirement since the amount of water in the cooling tower is reduced
   - Less excavation and lower material costs for large built-up towers with concrete sumps
   - Smaller tower may provide architectural and aesthetic benefits
3. Use smaller pipe sizes to dramatically reduce capital costs.
   - May reduce some pump energy savings because it increases pressure drop.
4. Invest capital cost savings from the pumps, tower and pipes in a more efficient chiller.
   - There is simply no substitute for high efficiency equipment.

Strategy #1: Reduce Condenser Design Flow Rates (Continued)

For Existing Systems:
Existing pumps can be used with lower flow rate and will use less power. If necessary, pump impellers can be modified for the lower flow rate or a variable frequency drive can be applied to the pump.

Existing cooling towers can be used with lower flow rate. Some modifications, like new water flow nozzles, may be required. The lower water flow through the cooling tower will actually cause the cooling tower approach temperature to be SMALLER. The same cooling tower, at design conditions, will now return colder water to the chiller. A tower designed for 85°F and 3 gpm/ton, when given 2 gpm/ton, will return water at nearly 83°F. This lower temperature will reduce the work requirement imposed on the chiller compressor and therefore reduce the energy consumption of the chiller.

When expanding chilled water plants, the same flow rate, cooling tower and pumps can be used to provide 50% more capacity. The new or additional chillers can be selected to operate with less condenser water flow rate than previous designs, which were typically at 3 gpm/ton.

Frequently Asked Questions

Is there a catch?
No, but with less flow you may notice the chiller will work harder. (Note the chiller energy consumption in Figure 3 increases slightly with reduced flow.) However, this is more than offset by pump and tower energy reductions, *improving the overall efficiency of the entire chiller plant.*

What is the ideal flow rate?
Optimal flow rate will vary from application to application. It is dependent on system components, and whether reducing capital cost or improving efficiency is more of a priority. There is significant evidence that the optimal flow rate will be very near 2 gpm/ton (1.8-2.2) for most applications.

Can this strategy work for absorption chillers, too?
Yes. Traditional design flow rates for absorption chillers vary by the type. Direct-fired absorbers have had the highest design flow rates at 4.5 gpm/ton. Today's absorption chillers can operate less than 4.0 gpm/ton, without a significant impact on efficiency or capacity.

Strategy #2: Reduce Chilled Water Flow Rate and Temperature

From the condenser water loop it has been demonstrated that lowering the water flow rate carries the benefits of reducing energy costs and reducing capital costs. This same concept can also be applied to the chilled water loop. We will consider all the components of the chilled water loop to discover the methods by which to simultaneously reduce energy costs and reduce capital costs.

Like the condenser water loop, a reduction in flow provides the opportunity to use smaller pipes for both energy and capital cost reduction.

Figure 4 shows examples of the effect of lower flow rates.

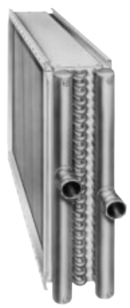
Figure 4

Tons	Pipe Diameter (2.4 gpm/ ton)	Pipe Diameter (1.2 gpm/ ton)	Est. Pipe Cost Savings	Pump Power Reduction
400	8″	6″	$ 10/ft	60%
600	8″	6″	$ 10/ft	50%
800	10″	8″	$ 15/ft	60%
1000	10″	8″	$ 15/ft	60%
2000	16″	12″	$ 50/ft	60%
4000	24″	18″	$ 50/ft	50%

Unlike the condenser water loop, there must be consideration given to the impact on the cooling coils. Reducing the water flow rate in the cooling coil will require the differential temperature (delta T) on the coils to be larger. Said differently, the coils must heat the water more because there is less water to absorb the same amount of heat from the air. As a result, the coils would need to be larger to allow the water to absorb the additional heat and raise the delta T. This would increase the cost of the system and defeat our purpose – but there is another way.

It is possible to retain the same cooling coil size and increase the delta T, by simply lowering the entering water temperature to the coil. See the example of coil performance with reduced flow and lower temperature, Figure 5. By using this strategy, the laws of science work to our advantage. By both lowering the entering water temperature to the coil and lowering the water flow rate through the coil, the coil will actually see an increase in the return water temperature; all with the benefit of retaining the same coil size as used in traditional designs. Using this strategy provides the ability to extract all the benefits of the low water flow rate without negatively impacting the chilled water loop operation.

Figure 5 – Cooling Coil Performance



Total MBH	476.5	475.6
EWT	44 F	41 F
Delta T	10 F	15.1F
GPM	95.3	63.0

Some facility managers have dealt with another issue called "low delta T syndrome." The "low delta T syndrome" occurs when the system is challenged to supply more water than is available at the specific supply water temperature. Said differently, the "low delta T syndrome" results when the water flow rate is at a maximum and there is not enough heat to drive the delta T to the desired level. As demonstrated previously, lowering the supply chilled water temperature provides an effective means to increase the delta T and provide a solution to the "low delta T syndrome."

The system optimization strategy of low temperature and low flow does not need to be confined to the chiller plant only. Lowering the supply chilled water temperature provides the designer with the opportunity to also lower the supply air temperature to the facility. The same laws of science that apply to water, as described previously, apply also to air. Colder air temperature results in the opportunity for the designer to further reduce both capital costs (by reducing the size of the air distribution system and the air handling units) and energy costs (by reducing the fan energy).

Summary of Cost Reductions

For New Construction:

1. Use smaller pumps to save energy and capital
2. Use smaller pipe sizes to reduce capital costs.
   - May reduce some pump energy savings because it increases pressure drop

Lower the Chilled Water Temperature to:

- Maintain original coil sizing or use existing coils without modification
- Prevent "Low Delta T Syndrome" or high flow when coils cannot get enough GPM to provide necessary cooling. At lower temperatures, coils can do more cooling with less water.

Lower the Supply Air Temperature to:

3. Use smaller Air Handling Units to save energy and capital
4. Use smaller ductwork to save capital
5. Reduce air-side system energy use
6. Invest the capital cost savings in more efficient equipment.

For Existing Systems:
An existing system can be converted to low flow by simply lowering the leaving chilled water temperature. The cooling coils will "automatically" reduce the water flow rate required since it is seeing a lower entering water temperature. The water flow in the system can then be re-calibrated to dramatically reduce the required system pump power. The return water temperature from the coil will increase by approximately the same amount as the chiller leaving water temperature is decreased. A low flow system is created.

Strategy #3: Control Condenser Water Temperature

In strategy #1, condenser water flow rate was discussed because chiller and cooling tower operation are affected by flow rate. Cooling tower and chiller operation are also affected by condenser water temperature. A cooling tower reacts to wet bulb, load and water temperature coming from the chiller. A given chiller reacts to the load and the water temperature returning from the tower. The goal is to find the best way to control this relationship.

The chiller and the tower react in different ways to the same condenser water temperature.

- As condenser water temperature *rises*, so does chiller power, but tower kW goes down.

Conversely,

- As condenser water temperature *decreases*, so does chiller power, but tower kW increases.

THE QUESTION: DOES THE **SUM** OF THE CHILLER AND TOWER kW GO UP OR DOWN?

	Chiller kW		Tower kW		Total kW
Hot (i.e. 85°F)	⇧	+	⇩	=	?
Cold (i.e. 55°F)	⇩	+	⇧	=	?

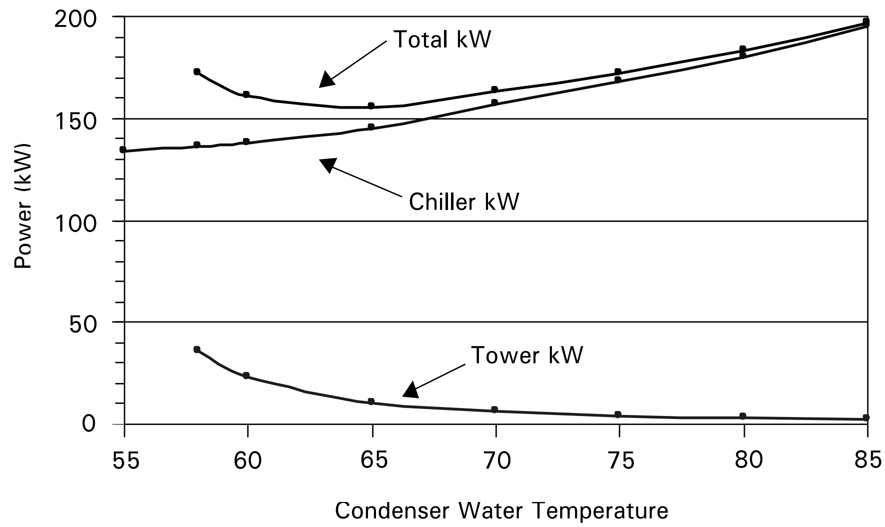
THE ANSWER: "IT DEPENDS!"

In order to minimize the summed energy consumption, we need to figure out how to control the condenser water temperature.

There are a number of frequently used method that represent the extremes in condenser water temperature control:

- Let the condenser water temperature stay at design (hot)
  - To minimize tower fan energy consumption
- Drive the condenser water temperature as low as possible (cold)
  - To minimize chiller energy consumption.

Figure 6 – System Energy Use (an example of 50°F WB)



There is a perception that each method optimizes the chiller plant energy usage, since each method minimizes the energy consumed by a single component. However, what is good for the chiller or tower may not be good for the system.

So what is good for the system? At some point between "as cold as possible" and "design," the total power consumption of the chiller plus the tower is minimized. This point fluctuates as a function of equipment, load and weather. The technology exists today to **find and operate to that point** through information sharing controls capable of monitoring and governing all areas of the HVAC system.

Figure 6 shows the power consumption at various condenser water temperatures for a given example system. Remember, the temperature for minimal power consumption changes based on the equipment, load and weather For instance, many weather conditions will not permit a cooling tower to produce temperature as cold as those shown in Figure 6.

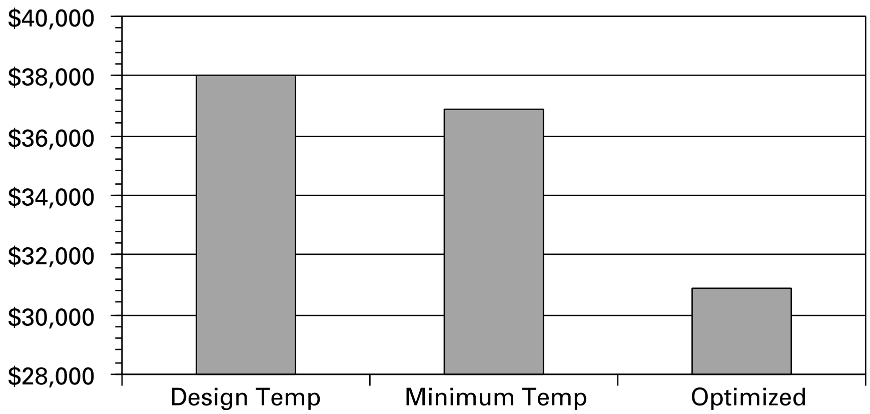
Is this strategy new? Not really. Chillers are rated in accordance with Air-Conditioning & Refrigeration Institute (ARI) standards. Similarly, cooling towers are rated in accordance with Cooling Tower Institute (CTI) standards. This practice assures dependable, repeatable performance for both types of equipment. Secondly, the temperature needed to minimize the total energy consumption of the cooling tower and chiller can be calculated using rated tower and chiller performance data. Thirdly, Trane has the product expertise and tools available to provide this optimization strategy for specific applications.

Energy savings of this optimized method of operating the condenser water loop verses "coldest possible" and "design" are demonstrated in Figures 7 and 8. The constants for these examples are:

- 500 ton chiller
- 0.58 kW/ton efficiency
- 85-95 F condenser water temperature difference
- 1,500 gpm (3 gpm/ton) condenser water flow
- $0.08/kWh
- $12.00/kW

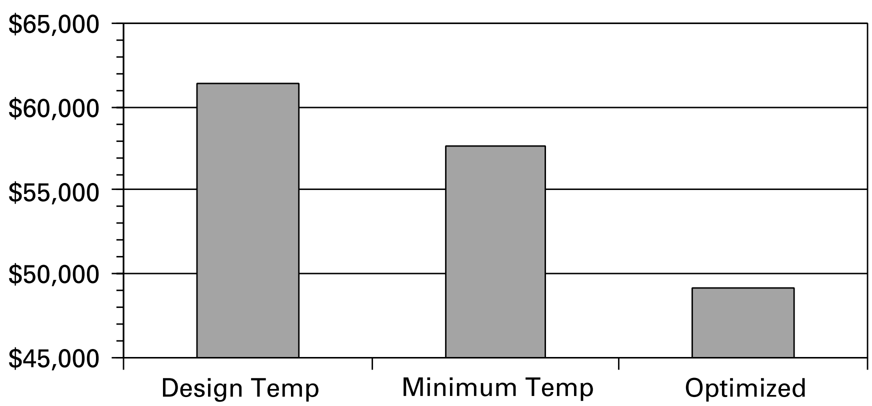
Optimization lets us save 23% over the design temperature set point and 19% over the minimum temperature.

Figure 7 – Chiller + Tower Estimated Operating Cost Yearly – Indianapolis



Even for very dry climates, like Arizona, the optimization saves 25% over the design temperature and 18% over the minimum temperature.

Figure 8 – Chiller + Tower Estimated Operating Cost Yearly – Phoenix, AZ



Summary

Use today's control technology to set the condenser water temperature for the lowest total energy usage of the chiller and tower. This intelligent temperature control can be based on real-time conditions.

Conclusion

The past 20 years have seen a renaissance in the energy efficiency of HVAC equipment, yet facility managers continue to be concerned about energy costs and the impact of the utility meter on today's decision-making process. With today's highly engineered and highly efficient water chillers, the make-up of the building's energy costs will look quite different than 20 years ago. This will require the both the facility manager the design professional to evaluate and optimize the entire chilled water system. True system optimization will examine the entire system including: chillers, water pumps, piping, cooling tower, air-side components and global controls, with the goal of simultaneously reducing capital costs and operating costs.

For more information

About condenser flow rates, see:

- Chan, Tumin, "*Oversized pumps, cooling towers can undersize the savings your chiller produces*," Engineered Systems, Vol. 16, No. 4, (April 1999): 46-47.
- Engineers Newsletter Volume 26, No. 2, August 1997, *How Low-Flow Systems Can Help You* available on the Trane web site: www.trane.com/commercial/library/archived_newsletters.asp
- Kelly, David W. and Tumin Chan, "*Optimizing Chilled Water Plants*," HPAC, January 1999 www.hpac.com - Register, select Magazine Archive then Feature Article Archive

About chilled water temperatures and cold temperature air, see:

- Coad, William J., PE, "*A Fundamental Perspective On Chilled Water Systems*," HPAC, August 1998 www.hpac.com
- Engineers Newsletter Volume 29, No. 2, April 2000, "*air distribution… Cold Air Makes Good $ense*" available on the Trane web site: www.trane.com/commercial/library/newsletters.asp
- Kirkpatrick, Allan T. and Elleson, James S., Cold Air Distribution System Design Guide. ASHRAE, 1996. www.ashrae.org
- Knebel, David E., "*Why 55°F?*" Engineered Systems, January 1999:136-153 www.esmagazine.com
- Maybaum, Michael W. "*A Breath of Fresh Air*", Building Operating Management, January 1999: 21-22 www.facilitiesnet.com/bom

About condenser water temperature control, see:

- Engineers Newsletter "*Tower Water Temperature…Control it How??*!" Vol. 24 No. 1, 1995 www.trane.com/commercial/library/newsletters.asp
- Schwedler, Mick, PE, "*Chiller/Tower Interaction, Take It To the Limit – Or Just Halfway?*" ASHRAE Journal, Vol. 40, No. 7, (July 1998): 32-39.

Design Tools:

Quick References for Efficient Chiller System Design, The Trane Company, CTV-TRT001-EN

System Analyzer™, The Trane Company

TRACE® 600, The Trane Company

DOE-2, U.S. Department of Energy

TRANE®

The Trane Company
An American Standard Company
www.trane.com

For more information contact your local district office or e-mail us at comfort@trane.com

Literature Order Number	CTV-SLB005-EN
Date	June 2000
Supersedes	New
Stocking Location	La Crosse