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Alternative Cooling Sources for Data Centers

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1. Introduction

The intent of this course is to educate data center designers and engineers about alternative cooling options and methodologies. It is assumed that the audience is familiar with basic air conditioning design and perhaps typical data center design techniques. The material will show several techniques for using alternative sources for heat sinks to support a data center. The reader should also have a basic understanding of water properties as well as pumps and approximate operational temperature ranges.

As ASHRAE and others aim for buildings to achieve net-zero energy use, including energy-intensive mission critical facilities, by the year 2030 designers will need to consider alternate cooling systems that can be reliable and more efficient. The tools and design techniques to achieve this goal are targeted to be in place by 2020; this is less than 5 years.

With the expansion of cloud computing and increasing demands for online services, data centers will be growing throughout the world. As the need for energy to support these data centers rises, the need to find and use efficient cooling sources will also increase. Using electricity from power plants to generate cooling is less efficient than using more localized cooling sources. To reach the energy saving goals, designers will need to broaden their choices to find the most beneficial options available.

Options for geothermal and utilizing water directly from rivers, lakes, and oceans has become a viable option for end users to save energy, avoid ozone depleting refrigerants, and save space. Geothermal systems will be presented to see the possible benefits and costs that might be associated with installation and maintenance. Lake and river water will be reviewed for the history of industrial cooling and applicability for data centers. To meet the high reliability standards for data centers, the potential advantages, disadvantages, and lessons learned from the unexpected will be reviewed. Lastly, effects to the surrounding environment will be discussed based on existing projects from around the world.

The first system in the U.S. at Ithica, NY, which serves about 51 megawatts of cooling starting in 2000, will be presented for lake water use. A data center in Hamina, Finland will be reviewed for using seawater. The potential efficiencies, comparisons of savings of equipment and other advantages and disadvantages are also illustrated. For data centers and other critical facilities, the additional requirement to meet higher reliability standards will also be reviewed.

2. Water Sources

For most heat transfer applications water is the best medium for moving and rejecting heat. Water can move more heat per unit (gallon or liter) than another other liquid, and it is far more efficient than air systems; because of this chilled water is often used to pull heat from airstreams and water-cooled equipment. Water is most dense at 3.98 degrees C, which is the temperature most often found for deep lakes. Since about 3% of the water on earth is fresh water, systems are being designed to operate with salt water and other non-potable water sources.

Geothermal and other alternate systems offer several benefits including no fresh water use, reduced space for equipment, and no noise that is associated with cooling towers or similar systems. Refrigerant volume is also reduced or eliminated, and lower needs for protection from weather degradation, vandalism, as well as protecting operating personnel from hazardous space conditions.

Rivers have long been utilized to support power plant operations. The water temperature of rivers tends to vary the most and they are also more closely regulated upstream, downstream, and across borders of nations.

Lakes have a more constant temperature according to the depth available, as the deep water within a lake is less effected by weather and other events.

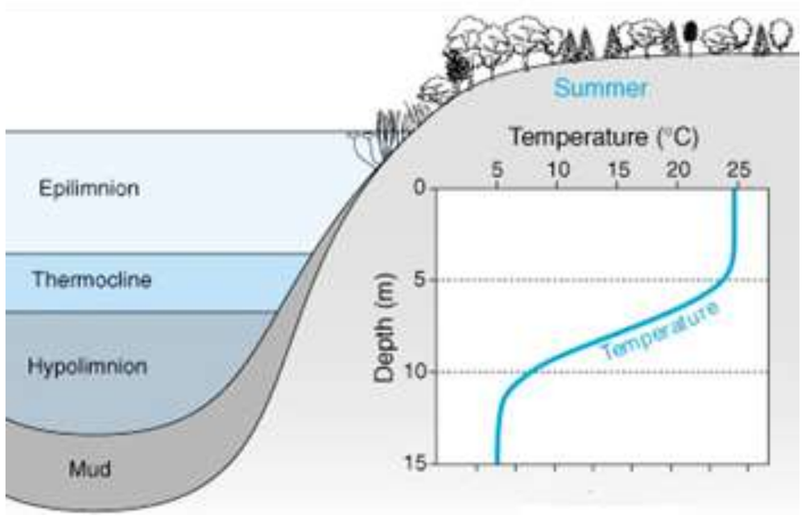

Figure 1: Thermoclines for a typical lake in North America with summer gradients.

Ocean water, like lake water, has wide fluctuations of temperatures at the surface. However, just like a lake, the ocean water temperature approaches a more constant year-round temperature that can be used for cooling. Even in the most tropical locations ocean water can be reliable to achieve 15 degrees C at 500 meters below the surface and about 5 degrees C at about 1,000 meters.

For discussion here, geothermal systems are typically closed loops of piping used to transfer heat to and from the ground. The piping installation can be extensive, which may be cost prohibitive, but the system tends to be stormproof and mostly protected from other external incidents. With data centers that are only rejecting heat, saturation of the geothermal ground loop is an issue to be overcome. When the ground has absorbed too much heat, the cooling water returns from the loop at a higher temperature. As the system operates the temperature spirals upward. With no means of removing the heat from the ground, the operators will need to either let the field rest in a fallow state or use heat rejection equipment to quickly restore the geothermal field back to its original state.

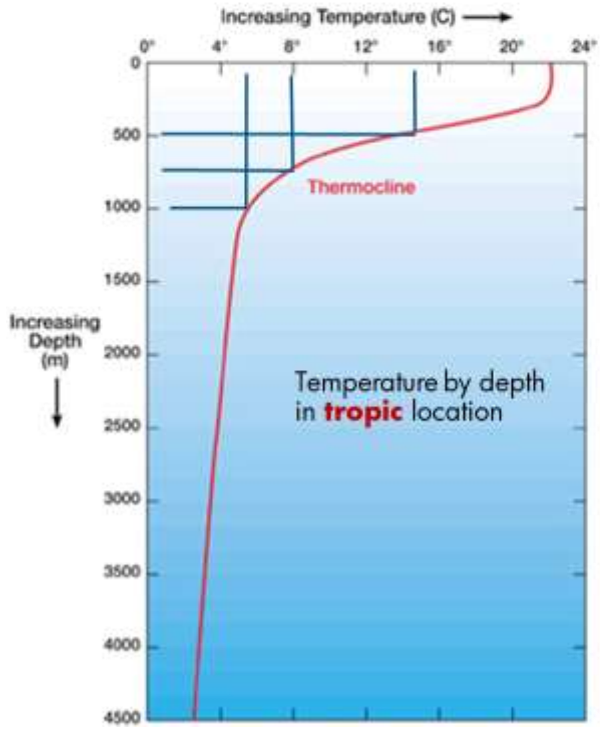

Figure 2: Average ocean water temperature by depth for most tropical locations.

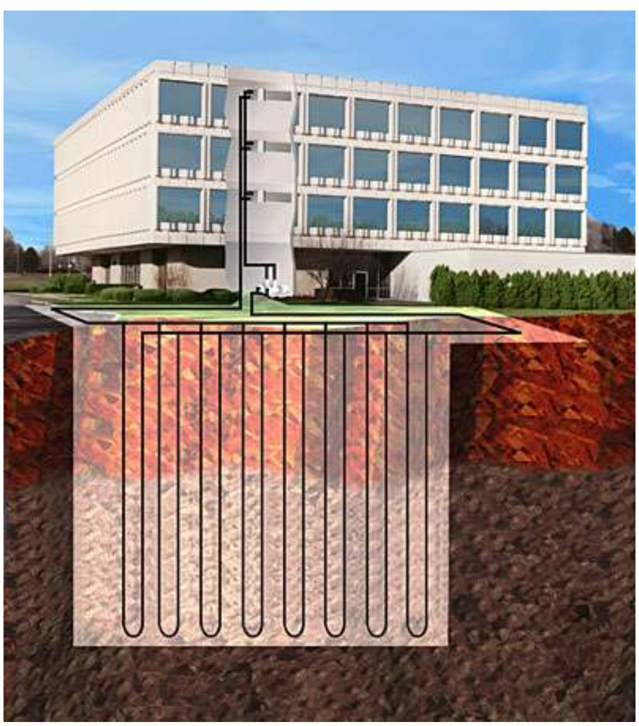
Figure 3: Vertical geothermal well field supporting a building is installed beneath ground features.

1 COOLING SYSTEMS COMPARISONS

1.1 Typical Cooling Systems

A typical cooling plant is composed of several pieces of expensive and sometimes sensitive equipment. The chilled water removes the heat from the load then uses a chiller to move the heat from chilled water system to the condenser water system. A cooling tower then rejects the heat to the atmosphere. Each water system requires pumps to move the water.

These systems require specialized care and at times complex operational and maintenance procedures. Based on the type of cooling refrigerants, there are hazards related to the personnel and the environment as well as standards and regulations on the minimum equipment performance, the type of accepable refrigerant per country, and other safety considerations for having and operating the equipment. Most of these existing systems also rely on evaporative cooling as the method to reject heat to the atmosphere, and the chemicals and water use has come under more scrutiny in the last few years.

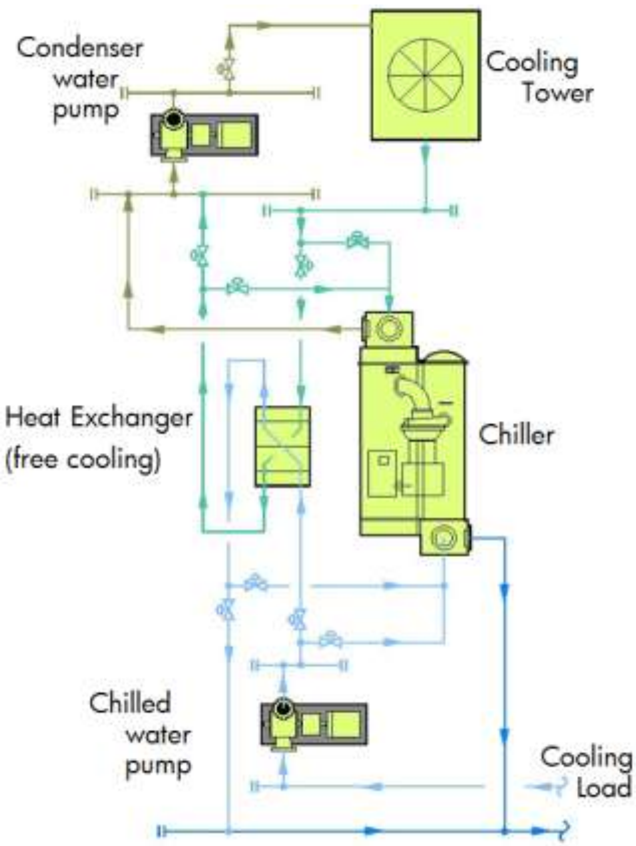

Figure 4: Typical chilled water plant with heat rejection to the atmosphere after several steps of moving heat.

Redundant components are installed to prevent loss of cooling during equipment failures. Since there are many operational components and complex modes of operation, loss of cooling may occur more frequently with inexperienced personnel or poorly maintained equipment.

1.2 Geothermal, River, Lake and Ocean Cooling System

A system utilizing a river, lake or ocean for heat rejection can be simplified by reducing or removing the refrigeration equipment. The refrigeration equipment, such as a chiller, can be removed if the source water temperature and flow can support the chilled water system temperature and flow needed. It may be also be possible to operate the chilled water system at higher temperatures to better match the water source temperatures more readily. It may be that the system can operate a significant number of hours per year without mechanical cooling, but a traditional cooling plant could be provided to avoid spikes in water temperature during periods of abnormally high temperature.

Geothermal systems in closed loops can act in the same manner as cooling towers, reducing the need for potable water and space that the towers normally need. For data centers operating at higher temperatures the geothermal water could be used more directly to centralized or unitary cooling equipment. Again, it should be noted that the geothermal system will need a means of heat rejection to ensure that the ground is not saturated with heat. Another strategy for a geothermal system is to use it as a base heat sink system with other equipment available as back-up.

Combinations of the above systems can also be used, with the heat sink replacing the cooling tower only or by providing a reduction in size or number of chillers and/or cooling towers. Such hybrid systems add complexity but typically still yield much better efficiencies than a traditional cooling plant system.

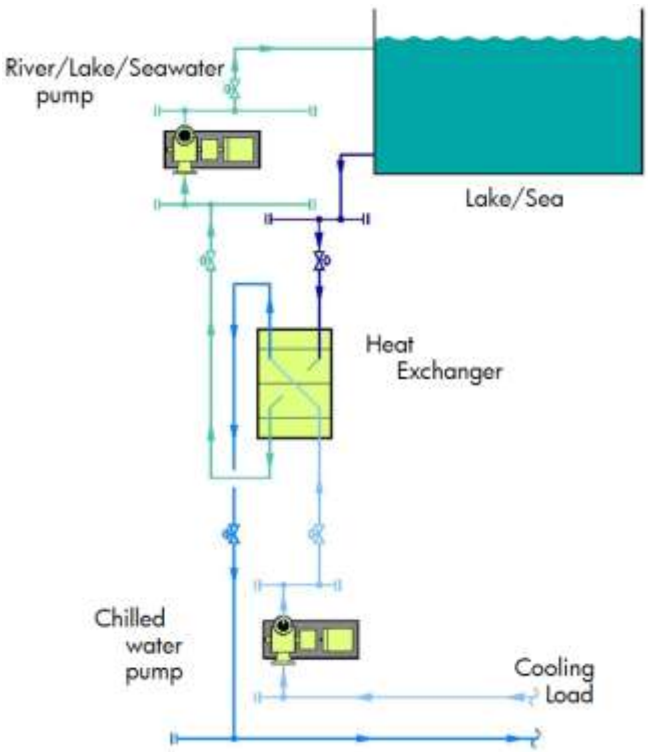

Figure 5: Cooling plant supported by River/Lake/Seawater for heat rejection.

1.3 Efficiency Comparisons

A high-efficiency, optimized chilled water cooling plant with all-variable speed drives and other energy saving measures will have an operational coeffecient of performance of approximately 6.0, which equates to about 0.6 kW per ton of cooling. This optimized cooling plant might have chillers operating at 0.4 kW per ton and the cooling towers at around 0.1, with the remaining energy of 0.1 kW per ton needed for the pumps. By comparison, the river/lake/seawater cooling system will not need the chillers or cooling towers. However, there may be more pump energy required as factors of location, height, water depth, and more should be considered. Even if the pump energy were doubled, the energy use compared to an excellent chiller plant is about one third. For a megawatt (MW) of cooling required the amount of savings would be about 0.135 MW; over the course of a year this would be over 1 million kWh. Additionally, since the river/lake/seawater system does not require potable water for heat rejection, over a million gallons of fresh water per MW of cooling load would be saved.

Efficiency Comparison Summary		
Equipment	**Traditional Chilled Water kW/ton**	**River, Lake, Ocean Cooling kW/ton**
Chiller	0.40 - 0.54	-
Chilled Water Pumps	0.05 - 0.08	0.05 - 0.08
Cooling Tower	0.08 - 0.12	-
Condenser Water Pumps	0.07 - 0.11	-
River/ Lake/ Ocean Pumps	-	0.08 - 0.13
Total	**0.6 - 0.85**	**0.13 - 0.21**
Minimum Difference	**0.39**	

Table 1: Comparison of traditional chilled water systems and river, lake and ocean water cooling

1.4 Relability Comparisons

Geothermal systems for data centers will likely be set as a reserve system to reduce load during peak demand times, if possible. The risk for river, lake and ocean water cooling systems from storms, watercraft, and biological sources (fish, shellfish, etc.) should be noted and explored based on the location. Although pumps can be placed in parallel, the piping for a river, lake or ocean water cooling is often not redundant. Due to this, the piping at the shore line can be buried or otherwise hidden since this is the most vulnerable section.

While typical mechanical plants are more flexible for location, they also have vulnerabilities due to having more equipment that can fail without a rigorous maintenance program. For high-availability needs, this can be an issue if personnel are inexperienced or not trained in the details of the system such as refrigerant types, condenser water treatment chemicals, controlling valves and energy management system, or balancing to achieve optimum efficiency.

2 EXISTING SYSTEMS

There are many projects around the globe where river, lake and ocean water is used for purposes beyond industrial, and many of these locations are where electricity, fuel and water are not abundant. Among the best locations are islands, and such projects are either in design or underway, such as Mauritius and

Honolulu, HI, USA, or complete, such as the HSBC Building, Hong Kong and the more detailed examples below.

2.1 Cornell Lake Source Cooling Project

Cornell University in Ithica, NY, underwent the first lake source cooling project in the USA. The system began operation in 2000 and supports 50 MW of cooling load for the university as well as other buildings in the city. The cost was about US$59 million and offset the cost of 6 new chiller plants on the campus. By comparison with the old chiller plant systems the average energy savings is about 86%.

The lake source cooling system draws from a depth of 76m to get water at 3.8 to 5.0 degrees C. This water is then cycled through a heat exchanger near the shore of the lake then back out to the lake at a depth where the outlet temperature matches the average stratified lake temperature.

The cooling water system for the university is a closed loop and therefore needs less water treatment. Pumps supporting the water flow on each side of the heat exchanger operate as needed to ensure adequate cooling is available for the university year-round.

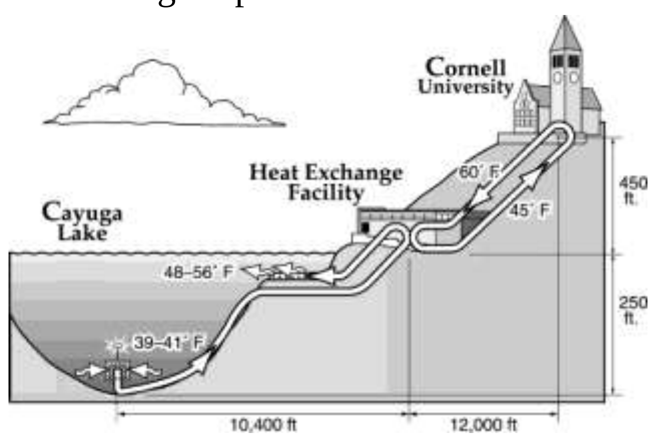

Figure 6: Cornell Lake Source Cooling project schematic diagram.

Before, during, and after the lake source cooling project Cornell University studied the environmental impact of the project as well as the impact of two other nearby waste water treatment plants. The annual reports for over 14 years show that the weather and tributaries had the most impact on the temperature, phosphorus, fluorescence and other measured items. In addition, the waste water treatment plants had larger attributed impacts to the lake than the lake source cooling project.

2.2 Ocean Cooled Data Center

In 2009 Google purchased a former paper plant in Hamina, Finland originally built in 1954 and converted it into a data center. The original building used a sea water tunnel 450 meters long for cooling and this was reused for the data center. Since the location is on the Gulf of Finland, the water temperatures are consistently cold at 1 to 3 degrees C; the tunnel is far enough below the surface to avoid any issues of freezing. The building went operational in May, 2010 and has been touted as one of their most energy efficient data centers.

Figure 7: Inside the data center cooling plant; rows of pumps flank their associated heat exchanger.

In addition to the data center being able to use a low temperature, the discharge back to the Gulf of Finland is tempered with fresh seawater to discharge water back into the gulf at temperature closer to the the intake to minimize the environmental impact.

3 WATER SOURCE RISKS

Rivers, lakes and oceans all have changes that happen over time. While a traditional chiller plant has equipment failures, the piping for a river, lake or ocean cooling sytem may endure stress in the future as the supports beneath change with the underwater landscape.

Geothermal systems are largely protected from storms and other external forces since the piping is installed below ground. However, a geothermal system has its performance limited by its size. As the heat rejection for a data center is continous, the potential for saturation of the geothermal well field grows as it is used. Operators may wish to use the geothermal system during peak electrical demand periods during the warmer months to reduce energy costs and still maximize the use of the geothermal system.

In each country government agencies exist to oversee the installation and operation of the projects. In many ways these agencies can be similar to that of a utility such as electricity or potable water supplies. Since there are a large number of industrial sites throughout the world the agencies have a wide range of experience and will work with the design. Since a river, lake or ocean water project is only rejecting heat and not altering the water quality most authorities will allow a project to move forward. Where these sources are not available, geothermal can be considered to achieve deep savings while within close proximity of the building.

For rivers, risks of sandbars, century-low river flows and other dangers should be examined to determine whether mitigation strategies would be warranted. Although they occur less often than earthquakes, tornadoes or other disasters, the hazards should be examined thoroughly.

Lakes pose less risk than rivers since the water flow, temperature, and shifting from flooding is much less likely.

Ocean water cooling systems have a few other issues to condend with, such as continental shelf and slope shifting on downward or lateral directions. Also underground tunneling may be considered to avoid wave action and disturbance by others.

The risk of pipe failure, although similar in possibility to failures of a traditional piping systems, may require additional time and resources to location and fix or replace a failure. However, if the failure occurs underwater, the river, lake or ocean water system may continue to operate as normal and wait for a planned outage for repairs. When operating a data center, other means of redundancy may be required.

Piping failure of geothermal systems is usually found during the installation. Other causes, such as corrosion, are not typical. And should a geothermal well fail it can be quickly isolated to allow the rest of the system to continue operating.

4 CONCLUSION

As depicted above, the efficiency gains of geothermal, river, lake and ocean cooling systems are significantly large enough to examine the possibility replacing traditional cooling systems. There are many details to be examined, but with projected electrical price increases and grid reliability concerns, leveraging the local resources to save energy, water and cost is becoming an easily viable option for most new and upgrade projects.

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