The energy-water nexus in district cooling

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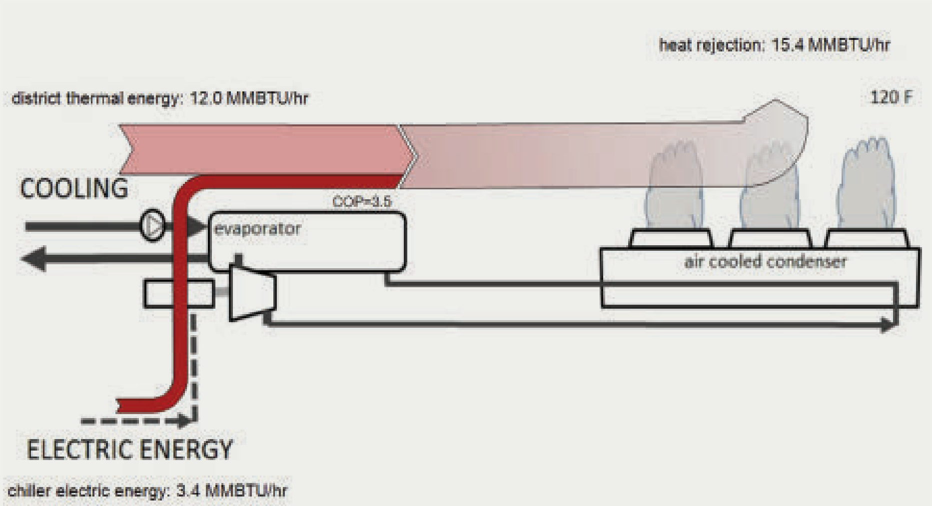
District cooling has become a fundamental service in many high-density urban environments, particularly in cooling-dominated regions with high annual temperature and humidity. It is difficult to imagine future growth and densification of cities like Dubai or Singapore without continuing expansion of their already-substantial plant and distribution infrastructure. Aggregation of building thermal loads into consolidated, energy-intense cooling nodes enables effective utilization of efficiency, sustainability and resiliency strategies that are often not financially viable on smaller scales. These include combined heat and power, thermal energy storage and microgrid integration. An interesting nexus of interconnections and tradeoffs exists between consumption of water and energy in urban air conditioning, enabling district cooling to assume a leadership role in more sustainable management of both resources.

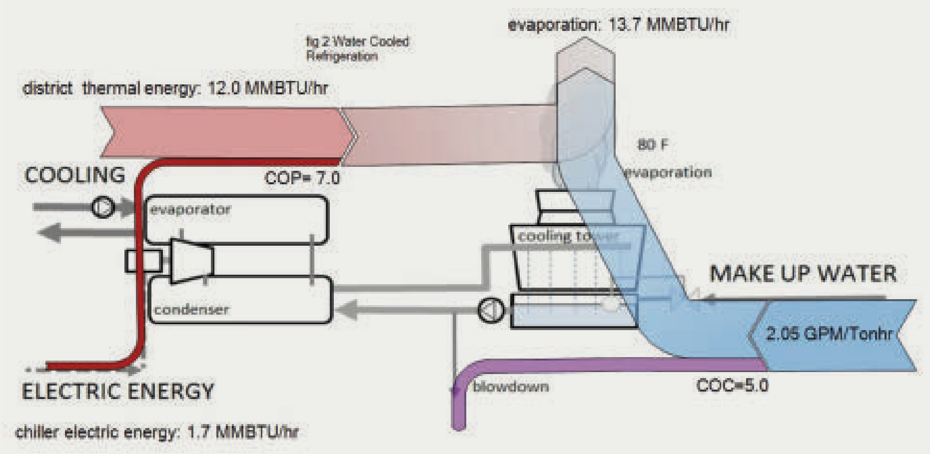
The engineering and economics of mechanical cooling in a hot climate rely on basic heat engine physics. The magnitude of electrical energy to drive refrigeration is in proportion to the difference between the temperature at which heat is extracted from buildings and the temperature at which the heat is rejected to the outdoors. The greater this temperature difference, the greater the energy input. Sankey diagrams, in which the width of the flow lines represents the magnitude of energy expenditure, depict this situation. In an example shown in figure 1, electric energy is used in an air-cooled system operating at an efficiency of 1.0 kW/ton (which translates to a coefficient of performance, COP, of 3.5) to reject individual unit or building heat into an ambient temperature of 120 degrees F. Compare this to the combination of energy and water used in a water-cooled system example, shown in figure 2, which rejects heat into an 80 F evaporatively cooled water stream, enabling operation at 0.5 kW/ton (or COP of 7.0). Under these conditions, an air-cooling refrigeration system requires twice the energy of the water-cooled alternative.

FIGURE 1. Air-cooled refrigeration.



Source: GLHN Architects & Engineers Inc.

FIGURE 2. Water-cooled refrigeration.



Source: GLHN Architects & Engineers Inc.

Taking advantage of this energy benefit, many district cooling plants have historically been designed with large evaporative cooling towers that recirculate through the refrigeration condensers. Notice in the diagram in figure 2 that the units of water flow have been converted into units of latent energy (Btu/hr) of evaporation at the rate of 1,000 Btu/lb. Water supplied to a cooling tower is rarely pure but includes minerals and salts that concentrate as evaporation occurs. High concentration of minerals recirculating through the refrigeration heat exchangers can drastically erode the efficiency advantage. A common method of managing mineral concentration is to drain off, or "blow down," a portion of the recirculating flow. Figure 2 shows a situation in which blowdown is controlled to maintain five "cycles of concentration," the volume of which corresponds to 25 percent of the water consumed in evaporation.

AS REGIONAL FRESH WATER BECOMES SCARCE, THE BALANCE OF TRADEOFFS BETWEEN COOLING ENERGY AND WATER CONSUMPTION BECOMES AN AREA OF SIGNIFICANT INTEREST.

Although an efficient water-cooled district cooling plant may consume as little as half the energy that building air-cooled alternatives do, it comes at the cost of water consumption on the order of 2 gal/ton-hr. In many situations in the past, this has not been a particularly high price to pay. In a mixed-use urban district in a region with extended high temperature and humidity, however, average per capita demand for cooling can be on the order of 0.5-1.0 ton-hr. The volume of water evaporated for air conditioning in this situation approaches the volume of water used in routine human activity (50 gal/day/person). As regional scarcity of fresh water becomes a concern and overall strategies are developed to better utilize available resources, the balance of these fundamental tradeoffs between cooling energy and water consumption becomes an area of significant interest.

Reliable supply of fresh water is accomplished through policy, urban planning and investment in infrastructure. Water cost rates, demonstrated to be effective tools in regulating human behavior, are seen to be increasing, often at rates exceeding the rate of rise in energy costs. Strategic development plans and tightened building codes related to water use are being adopted by many municipalities. Consumption and production technologies, ranging from improvements in household plumbing fixtures to seawater desalination are being adopted.

District energy will play a large role in the reduction of urban water consumption. Intriguing alternatives to fresh water consumption for cooling are developing. Use of treated sewage effluent as a cooling tower makeup source is becoming a mature technology in the Middle East and is being applied elsewhere. Hybrid air-water systems, capable of switching from air-cooled to water-cooled in response to electric and water price signals have been deployed. District-scale heat pump systems, often with ground-coupled thermal storage, are well-proven in areas in locations with both annual heating and cooling loads. Further reductions in costs of renewable energy production and storage are beginning to make the economics of a combination of photovoltaic electricity-powered, air-cooled chilling and thermal (and/or battery) energy storage a financially viable alternative. While fundamental physics still prevail, innovative ideas, such as a cooling tower plume water recovery scheme recently published by a team of engineers at MIT, may be on the horizon.

Consideration of the energy-water nexus is becoming an essential element in the planning and design of district cooling systems intended to operate over 30-to-40-year lives. With water costs on the rise relative to energy costs, a particularly important metric in considering regional alternatives is the ratio of the unit cost of water to the unit cost of energy, the water-to-energy cost ratio. Planners and designers of district cooling systems need to include this parameter when considering lifecycle economics of plant investment decisions. Continued investment in research and development is essential.

District cooling systems are well-positioned to take a lead role in managing energy and water in the urban environment.

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