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District Energy Enters The 21st Century

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ABSTRACT

The concept of district energy is undergoing a resurgence in some parts of the United States and the world. Its roots in the U.S. date back to the 19th century and through the years many technological advancements and synergies have developed that help district energy efficiency. This article explores district energy and how ASHRAE has supported the industry over the years.

DISTRICT ENERGY'S ROOTS

District energy systems supply heating and cooling to groups of buildings in the form of steam, hot water or chilled water using a network of piping from one or more central energy plants. The concept has been used in the United States for more than 140 years with the first recognised commercial district energy operation originating in Lockport, N.Y. circa 1877. The November 19, 1881, issue of *Scientific American* featured a front page story with illustrations describing the commercial venture in New York City associated with production and distribution of steam for building heating, motive power and cooking. The New York Steam Company installed a network of pipes to distribute steam produced in boilers as well as waste steam from electric production (See figure 1).

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NEW YORK, NOVEMBER 19, 1881.

Figure 1: November 19, 1881 Scientific American magazine cover showing steam piping installation in New York City. Image courtesy of David Wade, RDA Engineering.

The district heating concept grew in urban areas and was preferred where in-building boilers needing attendants and fuel deliveries could be avoided. Commercial systems, along with systems serving groups of institutional buildings, were initiated and prospered in the early decades of the 1900s and by 1949 there were over 300 commercial systems in operation throughout the United States. Of course, systems in the major cities of Europe also gained favor in Paris, Copenhagen and Brussels. In many cases district steam systems were designed to accept waste steam from urban electric production and became a revenue center for growing electric utilities in the United States.

After World War II, economic conditions changed in the United States and steam district heating systems lost favor for several reasons, including population shifts to the suburbs, electric generation plants being constructed remotely from downtown areas, and rapid growth of the natural gas distribution industry. Since the electric side of the utility business seemed to have unlimited growth potential, the steam district heating business in many cases were neglected or abandoned. Institutions where a profit motive was not dominant but continued customer service was dominant continued operation and expansion of district systems, seeing clear life-cycle advantages.

In Europe, a tradition of hot water district heating began early and was continued after World War II as part of major reconstruction efforts. European designers recognized the benefits of hot water distribution compared to steam with regard to lower heat loss, less maintenance requirements and synergistic interface with combined heat and power (CHP). Other factors contributing to widespread adoption in Europe are planned communities, lack of natural gas distribution, air quality concerns, and reduced reliance on imported fuels.

District cooling, in the form of chilled water service, was first offered as a utility in Hartford, Conn., in 1963. The system was developed by the Connecticut Natural Gas Company as a way to use natural gas for air conditioning.

Similar systems were developed within five years in Pittsburgh and Tulsa. Those systems continue operation through the present day.

Interest in district energy systems in the United States was renewed after the Energy Embargo of 1973 when the U.S. Department of Energy (DOE) undertook a series of programs to evaluate community energy systems using district heating and cooling through interface with power plants. DOE also explored the potential to provide low grade heat to large metropolitan areas from nuclear plants located nearby. This program encouraged new hot water district heating systems in St. Paul, Minn., Piqua, Ohio, and Jamestown, N.Y. The program was terminated in the early 1980s, and subsequent fuel price uncertainties reduced (but did not eliminate) interest in district heating and cooling as a commercial venture.

The reason district energy is not more widely used in the U.S. is largely institutional, rather than technical.[1] Most U.S. buildings are conceived, designed and constructed by individuals who rarely consider the energy characteristics of surrounding buildings. U.S. codes and design protocols deal with energy use at a single building, rather than on a community scale. Private utilities in the U.S. reinforce this approach through their focused marketing of electric or natural gas service. Furthermore, unlike other places in the world, there is not a coherent U.S. energy policy to incentivise development of district energy systems.

Even the most efficient buildings require a grid to balance annual energy production and use. Many think of the grid as only electricity; however, the possibilities for energy efficiency expand greatly when a district energy thermal grid is available.

European countries that are committed to reduction of greenhouse gases have made district energy systems a major component in their national energy strategies and policies. They recognise that a thermal grid gives them the most flexibility and energy independence when integrating conventional fossil fuels, nuclear energy, biomass, wind, solar and geothermal energy. Many systems there are base loaded with heat generated by municipal refuse incineration and waste heat recovery from electric generation. Low temperature hot water systems* can interface directly with heat from solar energy collectors or heat from heat pump systems.

CONCEPT OF DISTRICT ENERGY

District energy is not for everyone. It is a very technical and economic decision that requires a detailed analysis (see *2012 ASHRAE Handbook—HVAC Systems and Equipment, Chapter 12*) looking at the alternatives in both a quantitative and qualitative manner. For most, this decision is similar to whether one drives your car or take public transportation to work. On public transportation, for example, one can work or sleep or stay productive in lieu of focusing your efforts on fighting traffic and driving yourself. On the other hand, using your personal car, one can go from place to place at your own schedule and convenience, albeit at a probable higher cost. Of course, pros and cons exist for each method, and many factors affect your decision such as whether you live close to a bus or train line or not.

WHERE TO APPLY DISTRICT ENERGY

District energy for heating or cooling works well as an alternative to boilers and chillers in each building when the following factors are present.

High load-density facilities (i.e., short distances of distribution piping can interconnect several buildings of reasonable size) such as airports; college and university campuses; large hospital complexes; large office and industrial complexes/campuses; casinos; sports stadiums and arenas; and downtown central business districts of larger urban centers.

There is a high degree of diversity in building types served (office building, entertainment, retail, class rooms, residential and hotel, sports facilities, etc.).

Newer mega-developments where the infrastructure for power and water utilities may not be mature, reliable or adequate (e.g., United Arab Emirates, Qatar, Bahrain, Saudi Arabia, etc.).

Where the flexibility of using multiple fuels to hedge against volatile energy rates is considered important

Where a campus setting would be enhanced by locating noisy equipment and service vehicle access at a centralised location where these issues can be addressed aesthetically.

Existing buildings have extremely old equipment or new or proposed buildings are in planning or early design phases.

Where the replacement cost is high compared to a connection cost or significant capital can be saved upfront in the development of the project.

Where equipment is old and inefficient and must be replaced.

High replacement costs occur when the equipment is located in the penthouse of a high rise and removal and replacement would require helicopters or breaking down the equipment for removal or installation.

Longer paybacks are palatable (government facilities, airports, college and universities, hospital campuses, etc.).

Architectural features of a significant or historic building would be adversely affected by cooling towers or boiler stacks.

Conversely, district energy does not work well when the buildings are too small or too far apart from one another (increasing distribution costs); have newer highly efficient existing HVAC systems; or when the system developer requires rapid payback on their investment. Many times several of the previously listed factors must occur for a project to germinate.

EXPECTED BENEFITS

As highlighted in *ASHRAE's District Cooling Guide*[2] and the *2012 ASHRAE Handbook*, when a net present value (NPV) analysis is conducted comparing the costs of connecting to a district cooling system to constructing a building specific cooling plant, the results are extremely competitive and most times financially equivalent or superior. With comparable, NPVs building owners have the following benefits in connecting to a district energy system.

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* Low-temperature hot water district heating is defined as having a supply temperature equal to or lower than 121°C; however, it should be noted that many systems, especially in Europe, operate at much lower temperatures and often they also use seasonal temperature modulation, i.e., temperature reset based on outdoor temperature.

- Freeing up initial capital expenditure of the cooling plant to spend on other features.
- Improved building aesthetics. Architectural freedom with increased building aesthetics due to the cooling towers being eliminated from the roof top – freeing up space for other uses.
- Use and lease of the building square footage typically occupied by the chiller plant (basement or penthouse location).
- Reduced maintenance costs and/or staff are freed up to attend to additional duties or staff can be reduced accordingly.
- Reduced electric load with a flatter profile for potentially lower electrical rates.
- Reduced water treatment and water/sewer costs.
- Reduced emissions (easier and less costly to control).
- Easier and less costly administration costs.
- Potential reduced liability and associated insurance costs.
- Easier and less costly to provide for equipment backup.
- Ability to more easily use a variety of fuel/energy sources.
- Ability to more easily incorporate technologies such as thermal storage (TES) and combined heat and power (CHP).

DISTRICT ENERGY EMERGED AS A UTILITY

Some readers may be surprised to know that there is a district energy system in their state or serving their capitol, and that many major U.S. cities have examples of commercially operated district energy system such as Atlantic City, Baltimore, Boston, Chicago (two systems), Cincinnati, Cleveland, Denver, Detroit, Hartford, Houston, Indianapolis, Kansas City, Lansing, Las Vegas, Lincoln, Los Angeles, Miami, Minneapolis, Newark, New Orleans, New York City, Oklahoma City, Omaha, Orlando, Pittsburgh, Philadelphia, San Diego, San Francisco, Seattle, St. Louis, St. Paul, Trenton, Tulsa and Wilmington.

Additionally, several cities that had district heating systems enhanced their portfolio by offering a district cooling to existing customers. This was a much easier "sell" to the customer since they were already an advocate of district energy.

Moreover, the U.S. Capitol and many other federal buildings are served by a district energy system that is currently undergoing a major modernization.

Many of these district energy stalwart providers continue to upgrade their equipment and infrastructure to improve efficiency and reliability and become better environmental stewards. The district energy system in St. Paul, Minn., continually updates itself with the addition of chilled water thermal storage tanks; a CHP system that obtains heat from a biomass boiler that burns urban wood residuals; and solar hot water heaters that supplement the low temperature hot water distribution system. The St. Paul system is the largest district hot water system in North America.

Similarly, the district heating system in Seattle implemented renewable energy in the form of a biomass boiler fed from clean urban waste wood to generate the steam for their system. The U.S. also can boast that Denver hosts the oldest continually operated commercial district heating system in the world dating back to 1880. New York City has the largest district steam system in the world, serving approximately 1,800 customers. Recent activity in district heating growth has been in Montpelier, Vt. Several municipalities have studied its feasibility, including Crystal City, Va., indicating that there is still growth and interest in new developments.

District cooling grew rapidly in urban markets in the mid to late 1990s due to several factors that created the perfect storm of the application factors listed previously for system development. First, there were many buildings from the post-World War II building boom that had aging cooling plants that required replacement or retrofitting due to age of the equipment. Second, the majority of the refrigerants in use were chlorofluorocarbon-based, which the 1987 Montreal Protocol and the U.S. EPA Clean Air Act of 1990 dictated their phaseout by 1995. Therefore, building owners were dealt a double whammy in trying to address the clean air act and aging equipment. While drop-in refrigerants were developed and used successfully in chillers, they derated the output capacity, thereby making a connection to district cooling more feasible.

Third, several U.S. states were in the process of deregulating their electrical utilities so that a building owner could buy electricity from a producer other than their local provider who offered more attractive rates. In response to the threat of losing an entire building's electrical load, utilities created unregulated subsidiaries that developed electrically driven district cooling systems. Since a building's cooling load comprised about 40% of the electricity used, a district cooling provider could still lock up 40% of the building's electrical load while losing the rest of the building to another provider. Examples of this perfect storm that marked the surge of district cooling development are located in the downtown central business districts of Chicago, Houston, Denver, and Atlantic City.

TECHNOLOGICAL ADVANCES IN CHILLERS & SYSTEM CONFIGURATION

Since its inception in the mid-1930s, electric-driven centrifugal chillers have undergone several technological advances resulting in chillers today that are almost twice as efficient as when they were initially introduced. For example, in the 1970s the typical chiller efficiency was between 0.8 to 0.9 kW/ton (0.23 to 0.26 kW/kW) Efficiencies increased to around the 0.6 kW/ton (0.17 kW/kW) range from 1970 to 1990 and today depending on selection criteria, they can be below 0.5 kW/ton (0.14 kW/kW). There are many reasons for this improvement—more efficient compressor design, improved controls and instruments, addition of variable speed drives, enhanced refrigerant tubes, oil free compressors using magnetic compressor bearings, etc. These advancements can take advantage of both the district cooling provider and potential building customer. As stated previously, a potential customer with a newer highly efficient chiller plant makes the economics less favorable for a district cooling connection; however, there may be other qualitative reasons to connect to the system that may override the adverse quantitative reasons.

Furthermore, chiller plants have become more efficient with implementing variable water flow, applications of heat recovery and use of vapor compression chillers as heat pumps to generate low grade waste heat anywhere between 46°C to greater than 82°C depending on the size and type of chiller compressor.

Ball State University in Muncie, Ind., has the nation's largest ground-source, closed-loop district geothermal energy system where large centrifugal chillers that act as heat pumps in conjunction with 3,600 boreholes that generate both chilled and hot water for 47 campus buildings comprising 511 000 m^2. Competition is fierce among top tier institutions so not to be out done Stanford University is slowly phasing out its steam system and incorporating a heating and cooling regeneration system to serve the campus. The regeneration system uses large electric centrifugal heat recovery chillers to generate chilled water and low temperature hot water and incorporating both chilled water and hot water storage to serve the campus thermal needs while having a high coefficient of performance. These projects have spurred some district energy growth and analyses centering on heat pump technologies.

Additionally, as another twist of using the earth as a heat sink, West Union, Iowa, has recently implemented a central ground source geothermal district energy system that circulates what essentially becomes a condenser water loop for downtown customer buildings whom have water source heat pumps to connect to.

NATURAL SYNERGIES WITH OTHER TECHNOLOGIES

Many times due to the larger scale and diverse load profile of district energy plants, complementing technologies such as combined heat and power (CHP), renewable fuel use, thermal energy storage (TES) and heat recovery chillers can be implemented that could not be used on a smaller building scale. There are many environmental and energy efficiency benefits to district energy systems especially when CHP is incorporated and site vs. source energy is taken into account. Onsite power generation is typically over 75% efficient (usable energy out divided by energy in) as long as the waste heat is recovered and used in processes such district energy. For example, a typical simple cycle electric utility power plant is less than 33% overall efficient when taking into account the efficiency of combusting the fuel (gas, oil, coal) to generate the power and then transmit the electricity over substantial distance until it is transformed down and used by the customer. Hence, the site efficiency of CHP and district energy is greater than the inefficiency of source energy power plants (67%). Furthermore, localized district energy not only benefits a congested and inefficient electrical grid, but also benefits the environment by emitting fewer pollutants into the air and water.

CHP is common in several district energy systems that are commercial or institutional systems. One of the systems in Houston serves the largest medical center in the world and incorporates both CHP and TES into its plants. Boston and Cleveland also have similar systems.

Similarly, large scale TES systems are common in district cooling systems and in hot water district heating systems in northern Europe. The Europeans have found unique ways of storing thermal energy in objects other than tanks and have used underground aquifers for seasonal thermal storage. TES offers efficiency benefits to the chiller plant, and also to the local electric utility who may offer financial incentives for demand side management programs that assist greatly in the economics. For example, the new replacement central utility plant for Los Angeles International Airport is slated to receive a $2 million incentive from the local electric utility LADWP for a 15,000 ton-hour (52,753 kWh) and 5.7 millionL chilled water storage tank that will be operational in 2015.

DISTRICT ENERGY GROWTH AROUND THE WORLD

District energy is a universal concept that can be implemented just about anywhere when the conditions are ripe. The most recent growth in district cooling has been in Asia and the Middle East. District cooling has grown exponentially since the late 1990s in the Arabian Gulf region where the extreme climate requires cooling and the economic growth has generated many mega-developments that are served entirely by district cooling providers. The district cooling enterprises in the Gulf region also have become the new pioneers in the use of treated sewage effluent and seawater for condenser water systems due to the scarcity of fresh water.

Competition in the gulf region is fierce for district cooling with several successful district cooling entities established. The Emirates of Dubai and Abu Dhabi of the UAE have been extremely active in recent years in the construction of the mega-developments with the increase of coastline with manmade islands. Not to be outdone, there is a district cooling provider in Qatar that has a single plant totaling 130,000 tons, which serves the residential and mixed use mega-development *The Pearl*, Qatar – a manmade island.

On the other side of the International Date Line, there is huge activity in both China and South Korea who have mature systems and have seen significant growth in recent years. Not to ignore other regions of the globe, Germany is also blossoming with district energy systems. Great Britain has embraced the concept and is implementing several projects, which included the Olympic Park in London and systems in Birmingham, Nottingham, Sheffield and Southampton to name a few with many incorporating CHP.

Stockholm, Sweden, one of the meccas of Scandinavian district heating, is into district cooling in a big way with over 90,000 tons of cooling capacity served by multiple district cooling plants serving over 600 buildings. The district energy plants are highly efficient and most use large electric chillers as heat pumps with the Baltic Sea as the heat sink and also for free cooling. The heat pumps also create low temperature hot water for use in the wintertime for heating. Similar to Stockholm district cooling solution, another Scandinavian city known for its district heating is Copenhagen, Denmark, which recently implemented district cooling also using sea water from the Baltic Sea. Helsinki, Finland, also has district heating and cooling systems and uses heat pumps to provide the district cooling while capturing the rejected heat from the heat pumps for district heating.

Our neighbors to the north in Canada have also been extremely active with recent implementations of district energy systems in Markham, London, Sudbury, Toronto (with deep lake water district cooling), and Cornwall, and have over 130 systems operating currently in Canada.

Figures 2 and 3 summarise the recent growth reported growth in the district energy business. Figure 2 illustrates the North American (U.S. and Canada) growth from 2008 to 2013, and Figure 3 illustrates the growth beyond North America for the same time period. As can be seen, the North American growth is dwarfed by the rest of the world and the major growth sector for North American were university and health-care campuses, while the rest of the world had major growth in the mixed commercial use and residential markets.(Data courtesy of the International District Energy Association [IDEA]).

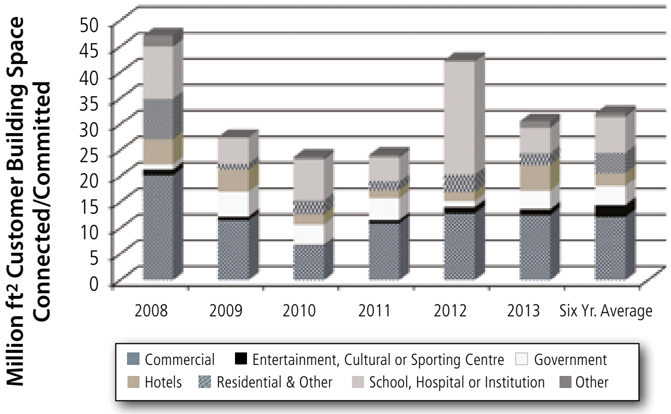

Figure 2: North American district energy growth from 2008 to 2013 in building area of new customers added.
Source: International District Energy Association.

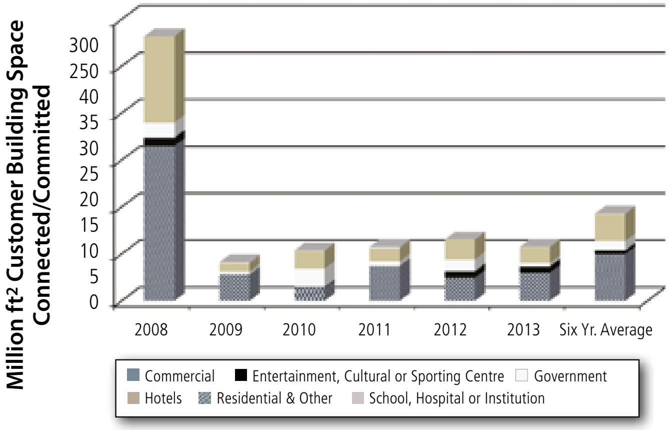

Figure 3: International district energy growth from 2008 to 2013 in building area of new customers added.
Source: International District Energy Association.

ASHRAE INVOLVEMENT IN DISTRICT HEATING AND COOLING

The ASHRAE technical committee (TC) for district heating and cooling is TC 6.2. This technical committee was originally formed in 1984 with the second-listed author of this article being the major force behind the committee founding. TC 6.2 is responsible for the district heating and cooling chapter in the *ASHRAE Handbook—HVAC Systems and Equipment*. This handbook chapter has undergone a title change and several major rewrites over the years each time increasing in length as well as being updated, more than doubling from 1980's to present.

Despite the increases in the amount of material contained in the handbook, TC 6.2 recognised the need for a more comprehensive document many years ago and in 1997 wrote a work statement to have it funded as an ASHRAE research project. This project was denied by the ASHRAE Research Activities Committee, and the TC eventually shelved the work statement where it remained for several more years until further need for a district energy guide arose due to the rapid development of district cooling projects in the Middle East. The Middle East ASHRAE chapters are very active and ASHRAE is relied upon for design guidance heavily.

The need for more extensive design guidance specifically for district cooling was emphasized in the fall of 2006 when the ASHRAE President was visiting the Middle East and Chapter members expressed the desire for a district cooling design guide to be developed. Upon President Townsend's return the request made its way through ASHRAE to TC6.2 which responded with a rewritten work statement. That work statement ultimately went to bid in the fall of 2007 with selection of the contractor occurring at the Winter 2008 ASHRAE meeting. Originally, a two-year performance period was projected, but a number of issues caused the completion of the project to be delayed.[3] Finally, in 2013 the project was concluded with two guides being published by ASHRAE, the first being the *District Cooling Guide*[2] in June 2013 and then the *District Heating Guide*[4] in September 2013. The titles of the Guides were changed from design guides as they contain planning and operating information as well as design.

The ASHRAE district heating and cooling guides were authored with the objective being to provide guidance that would be comprehensive and not limited simply to practices in North America. To that end several contributors visited the United Arab Emirates (UAE) to grasp a clear understanding of the practices there, where district cooling systems tend to be much larger than elsewhere. Several authors from outside of North America also contributed to the guides, which supplemented the wide international experience of many of the other authors. While in-depth coverage of all practices worldwide may not have been achieved, overall the content has an international flavor and should have wide applicability. It is expected that selected content from these new guides will be added to the ASHRAE Handbook chapter on district heating and cooling in coming years.

Similar to the ASHRAE Handbook, documents like the district heating and cooling guides must be continually revised to stay relevant to current practices. Further updates to the ASHRAE district heating and cooling guides will likely be accomplished as volunteer efforts by TC 6.2 members. Individuals who would like to contribute are encouraged to become active in TC 6.2.

CONCLUSIONS

District energy has a long history in the U.S and across the globe it has a bright future. While there will always be challenges with the continuing education of the technical world, district energy may be a beacon for energy stability and efficiency. While ASHRAE and other international professional societies and trade associations have supported district energy over the years, sometimes it still feels like a best kept secret. In closing, while district energy may not be everyone's "cup of tea," district energy does provide a palatable energy solution for many in the world, whether hot and/or cold. Perhaps you will be able to sample a taste in your city soon. ▮

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