REPORT ON THE BENEFITS OF ICE-BASED THERMAL STORAGE FOR DISTRICT COOLING IN THE UAE MARKETS

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SUMMARY

ADVANTAGES OF THERMAL STORAGE WITH 1.1°C WATER SUPPLY

1) Improves efficiency due to higher nighttime electric generation efficiency and lower nighttime transmission and distribution power losses.

2) Reduces cost of Distribution Piping and Pumping. Based on 100,000 ton district cooling system with and 12,500 meters of trench length the savings will be US$5.1 million.

3) Reduces the peak demand for power by 35% and therefore the cost of electric generation facilities that serve the area can be reduced. For a 100,000 ton cooling system the demand will be reduced by 35 MW which should result in electric generation cost savings of US$ 38.3 million.

4) Reduces the peak demand for power by 35% and therefore the cost of electric distribution and plant electrical system is reduced. For a 100,000 ton cooling system the demand will be reduced by 35 MW which should result in electric transformation & distribution cost savings of US$ 3.4 million.

5) Colder water supplied from the cooling plants results in less heat transfer surface in the heat exchangers that are in each customer building. For a 100,000 ton system with a diversity of 78% the installation cost savings will be US$ 1.7 million.

6) There will be 35% less cooling tower requirement. For the 100,000 ton system this will reduce the cost of the installation of cooling towers by $4.5 million.

7) The net cost adds at the cooling plants for adding the thermal storage in lieu of the 35% of chiller capacity that was eliminated is US$ 12.8 million.

8) There will be lower cost for installation of water treatment facilities. (Lower design make-up water through put rate by 35%).

9) If the lower water temperature is utilized in the customer buildings to reduce air unit and duct work sizes the construction cost savings will be approximately US$ 22 per square meter of usable building area. A 100,000 ton district cooling system would likely serve approximately 3.5 million square meters of build space so the potential saving will exceed US$ 75 million.

10) Reductions in emission of pollutants to the environment result from the reduced amount of installed electric generation equipment and the improved efficiency in the generation, transmission and distribution of electric power.

NARRATIVE ANALYSIS

The following narrative is provided to assist with the understanding of the reasons that District Energy Systems that use External Melt Ice-based Thermal Storage should be incorporated in any major, high quality, environmentally conscious developments in the UAE.

When combined with District Cooling technology Ice-based Thermal Storage is able to provide benefits in several important ways. These benefits are described in the following sections:

I. Impact of Ice-Based Thermal Storage on District Cooling Plant Technology

External Melt Ice-based Thermal Storage for Mega-size District Cooling Systems

The prior art for design of district cooling systems includes use of electric driven mechanical refrigeration equipment (chiller units) to produce water that is chilled to a temperature that is generally 5.6ºC. The installed chiller units in the cooling plants must have the capacity to meet the full cooling load imposed on the district cooling system. As a result this form of cooling technology requires the maximum use of electric power during daytime periods when the highest ambient temperature reduces the efficiency of both the cooling plants and the power generation facilities that provide power to the cooling plant equipment.

The all-chiller design has four major disadvantages when applied to large scale district cooling systems. An analysis of these disadvantages follows:

1) High Cost of Heat Exchangers used in the Buildings.

Many buildings connected to a district cooling system reach a height that requires heat exchanger to separate the pressure of the water within the building from the pressure of the water in the distribution pipes that are part of the district cooling system. If heat exchangers are not installed the distribution pipes would have a design pressure rating that is appropriate for the height of the tallest buildings connected to the system. For instance, an 80 story building would require piping and related components that are rated for a design working pressure of 3,500 kPa.

Since the prior art uses district supply water temperature that is nearly equal to the desired design supply water temperature within the buildings the heat exchangers must contain extensive heat transfer surface and therefore impose a significant cost on the cooling service supplied to the buildings. For example, consider a heat exchanger that serves a 2,000 ton building cooling load. The building supply temperature should be no higher than 6.7 ºC in order to assure adequate de-humidification at the building air handling systems and the temperature of the water returning from the building air handling systems will be no higher than 14.4 ºC.

Design which optimizes the sizing of the building heat exchanger and the flow rate of the district system will result in selection of the heat exchanger with the district supply of 5.6ºC and return of 12.2ºC and a building supply of 6.7ºC and return of 14.4ºC. For the 2,000 ton cooling load in consideration these temperatures will result in heat exchangers that contain approximately 1,040 square meters of heat transfer surface. This is more than 240% more heat transfer surface, and proportional cost, than is required for heat exchangers used in district cooling systems that employ Ice-based Thermal Storage technology.

Thus, the disadvantage seen for the all-chiller design is that due to its supply water temperature and the need to use heat exchangers to separate the water in the district systems from the water in the building systems, construction costs for the heat exchanger installation will be high.

2) <u>High Installation and Owning Cost of the Piping</u>.

With water that is supplied from the cooling plants at 5.6ºC and is returned to the cooling plants at 12.2 ºC (6. 6ºC T.D.), the minimum water flow area that is required to provide various rates of cooling capacity are listed in Table 1 immediately below. Also listed in this table are the pipe size and the area of pipe surface that is required at the given flow rates.

TABLE # 1

Tons	Flow Area Required (m^2)	Pipe Size	Surface Area Exposed to Soil (m^2/meter of pipe length)
30,000	0.862	DN 1050	3.35
20,000	0.630	DN 900	2.87
16,000	0.434	DN 750	2.39
12,000	0.274	DN 600	1.92
8,000	0.274	DN 600	1.92
4,000	0.118	DN 400	1.28
2,000	0.073	DN 300	1.02

As can be seen by comparison of this table with Table #2 that is on page 8 below, the pipe size selections that are based upon a 5.6 ºC supply and 12.2ºC return (6.6 ºC T.D.) are on average more than 60% greater in size and more than 30% greater in surface area than will be required for a district cooling system whose design is based upon Ice-based Thermal Storage technology.

These factors greatly impact the following construction issues:

1) The cost of pipe.
2) The cost of the labor to install the pipe.
3) The cost of the excavation and civil work required for the trench that will contain the piping.
4) The time required to install the pipe and trench.

In addition to the construction cost issues, a comparison of Table #1 with Table # 2 illustrates that the heat gain to the district chilled water piping will be approximately 12% greater for the piping in an all-chiller system than the piping in the system that uses Ice-based Thermal Storage technology. This statement assumes a soil temperature of 30ºC.

Thus, a clear advantage can be seen for a large district cooling system that is designed using technology that employs supply water temperature at 1.1ºC.

3) <u>Less than Optimum Performance at Partial Load Conditions</u>.

District cooling plants that utilize chillers to meet the entire cooling load will of necessity spend 80% or more of the operating hours at varying percentages of partial load. The large number of part-load operating hours results in significant inefficiency in the all-chiller plant operation. The chiller units as well as the condenser water pumps and primary chilled water pumps that serve each chiller unit will all consume near full electric power while providing less than full cooling capacity. The magnitude of the inefficiency thus introduced will depend upon the number of hours spent at part-load and percentage of reduced load operation.

Small chilled water plants can utilize variable speed chiller units and variable speed primary pumps to lessen the impact of this part load operation. However, this is not a practical approach for a large capacity chiller plant due to the high cost of variable speed drive units at the medium voltage supply level that must be used for the large chiller units.

Thus, the disadvantage seen for the prior art is inefficient operation at partial load. Designers focus on performance of equipment at full load but the profitability of a district cooling business rests in performance at off-peak conditions.

4) Less than optimum utilization of electric power and its resultant high cost.

District cooling plants that utilize electric driven chillers to meet the entire cooling load consume the greatest amount of electric power during daytime periods when the cooling load is the highest and coincidentally the demand for power at the generating station is the highest. The inability of the all-chiller plants to displace use of electric power to lower use periods requires installation of larger electric generating facilities that have lower average utilization.

For example, a 20,000 ton cooling plant that contains 10 – 2,000 ton electric drive chiller units will not operate at 20,000 tons of output capacity for all of the 8,760 hours in a year. Even in warm climates such as Abu Dhabi the annual use is expected to be no higher than an average of 6,850 ton during all 8,760 hours. This is due to the cooler temperature and low building use during night time hours and the cooler temperatures experienced during months such as December through March. The electric load factor that results from type of district cooling plant is 34% meaning that on average the electric power serving the plant is 66% under-utilized. It also meant that the capital invested in the electric power plant is 66% under-utilized.

Thus, the disadvantage seen for the all-chiller district plant design is higher construction costs for electric power plants, and as a result of poor utilization factors, higher unit cost for electric power.

The innovations brought to the district cooling industry through the use of External Melt Ice-based Thermal Storage technology address each of the main disadvantages of the all-chiller plant while improving the quality and reliability of the cooling service.

In a system that uses the External Melt Ice-based Thermal Storage technology the temperature of the water supplied to the district cooling system is 1.1°C. This is made possible by allowing water that has been chilled to approximately 6°C by mechanical refrigeration equipment to be drawn through an open tank of water that surrounds cylinders of ice that were formed during the previous night time hours. The cylinders of ice are on pipe coils that are installed in the open tank of water. During the night time hours a mixture of ethylene glycol and water is chilled to below the freezing point of water and then circulated through the pipe coils in the tank.

The features of the External Melt Ice-based Thermal Storage technology that allow it to significantly enhance the prior art of all-electric chiller units in District Cooling are as follows:

1) <u>Reduces Cost of Heat Exchangers</u>.

1.1°C water is supplied to the district cooling system by use of this Ice-based Thermal Storage technology. The selection of heat exchanger can thus be made at the following conditions: District Supply - 1.1°C, District Return – 12.2°C, Building Supply – 5.6°C, Building Return – 14.4°C. For the 2,000 ton cooling load in consideration above these temperatures will result in heat exchangers that contain approximately 300 square meters of heat transfer surface.

Thus, a major advantage introduced by External Melt Ice-based Thermal Storage technology is that the amount of heat transfer surface in the building heat exchangers is reduced by more than 70%. Therefore the cost of the heat exchangers is also reduced by approximately 70%.

2) <u>Reduces the Installation and Owning Cost of the Piping</u>

With water that is supplied from the cooling plants at 1.1°C and is returned to the cooling plants at 12.2°C (11.1°C T.D.), the minimum water flow area that is required to provide various rates of cooling capacity are listed in Table 2 immediately below. Also listed in this table are the pipe size and the area of pipe surface that is required at the given flow rates.

TABLE # 2			
Tons	Flow Area (m^2)	Pipe Size	Surface Area Exposed to Soil (m^2/meter of pipe length)
30,000	0.434	DN 750	2.39
20,000	0.274	DN 600	1.92
16,000	0.274	DN 600	1.92
12,000	0.188	DN 500	1.60
8,000	0.151	DN 450	1.44
4,000	0.073	DN 300	1.02
2,000	0.051	DN 250	0.86

By comparison of the factors listed in Table #2 with those listed in Table # 1 it is easily seen that the 40% reduction in flow rate that is allowed by supplying 1.1ºC chilled water, creates a reduction in the cost of construction of the distribution piping. The smaller pipe size and reduced trenching requirement suggests at least a 50% reduction in pipe installation cost when 1.1ºC is used.

Further, due to the smaller pipe surface area the amount of heat loss is reduced despite the colder water supply temperature.

3) Full Load Operation during daytime operation reduces Part Load Inefficiencies

During daytime periods the water returning to a district cooling plant with External Melt Ice-based Thermal Storage technology is cooled in series, first by chiller units, then by the melting ice in the thermal storage tank. This allows the chillers to be used at full load to control inventory of thermal storage rather than to be controlled to produce a specific chilled water temperature that must be supplied by the district cooling plant. This means that chiller units will be turned on only when they are needed and only at full load in order manage the inventory of storage. After the chiller units cool the water to whatever temperature that is dictated by their full load operation the melting ice will temper the water to its required supply temperature. Properly controlled this feature allows the chillers to provide cooling at 6ºC or higher which will be more efficient than the operation of chillers that always have to supply 5.6ºC.

4) Reduced Electric Demand and Electric Infrastructure Construction Costs

District Cooling plants that utilize External Melt Ice-based Thermal Storage technology meet approximately 30-35% of the peak cooling demand with stored cooling thus avoiding an equivalent amount of electric power usage during daytime, high electric use, hours.

The reduction in electric demand by the cooling plant results in fewer electric generation assets having to be dedicated to the district cooling plants. Eventually, the lower demand for power from the cooling plants translates into approximately a 20% reduction in the total amount of generating capacity required for a district that utilizes this advanced technology. Transmission and distribution infrastructure, and the associated construction and repair costs, also experience a similar reduction.

Using the example of the 20,000 ton cooling plant cited above, in a district cooling plant with storage 14,000 tons of electric chillers would be used to generate the total daily cooling requirement through cooling load leveling operating. The resultant electric power load factor will be greater than 66% or, more than a 25% improvement in load factor over an all-electric chiller facility.

Thus, another advantage introduced by External Melt Ice-based Thermal Storage technology is that total electric generation and infrastructure construction cost can be reduced while increasing the annual electric load factor.

There are other advantages that the External Melt Ice-based Thermal Storage technology has over the prior art. A list of these other advantage follows:

1) Reduction in the Size of Desalinization Facilities

In district cooling plants that utilize thermal storage the peak refrigeration capacity is reduced by about 30%. As a result, the peak output capacity of the desalinization plants, and equipment (pumps, piping, and storage vessels) within those plants, is reduced by a corresponding amount. Exact sizing and cost savings attributable to the reduction in equipment must be determine at a later stage of design.

2) Improved Quality of Cooling Service.

An improvement in the quality of the cooling service provided to the occupants of the buildings is achieved due to use of 1.1°C chilled water to control humidity to lower levels that is possible with district cooling plants that supply 5.6°C chilled water. Indoor relative humidity levels in the 42% to 45% range allow comfort conditions to be attained at higher air dry-bulb temperature than is normal for a cooling system that uses 5.6°C chilled water.

3) Reduced energy losses in Generation, Transmission and Distribution of Power.

There are three main factors that must be understood in order to properly evaluate the positive impact that a District Cooling system with ice-based thermal storage technology can have. These factors are:

a) The improvement of electric load factor at the power plant level results in greater fuel efficiency. Data in the table below on Solar gas combustion turbine generators illustrates the improvement in efficiency that occurs as a result of operation at a greater load factor

SOLAR TURBINES - TAURUS-10301S PERFORMANCE MAP						
	Inlet Air Temperature					
Percent Load	50°F	60°F	70°F	80°F	90°F	100°F
100%	10,278	10,405	10,532	10,728	11,039	11,350
90%	10,485	10,641	10,796	11,032	11,407	11,781
80%	10,799	10,952	11,104	11,335	11,707	12,079
70%	11,514	11,681	11,848	12,098	12,503	12,908
60%	12,421	12,613	12,804	13,087	13,541	13,994
50%	13,569	13,793	14,017	14,344	14,861	15,378

Presuming that cooling plants were 60% of the output of a generating station and that all of the cooling for the area was provided by a district cooling plant with ice-based thermal storage the improvement in energy efficiency would be 12.6% based upon the improved load factor alone.

b) The second factor that must be acknowledged is the improvement in energy efficiency due to the greater use of power during the night time period when the average ambient air temperature is 20.2°C versus

31.5°C during the daytime. Inspection of the table above indicates that the improvement in efficiency is equivalent to about 5.2%.

c) Finally, there is improved efficiency in power supply at night due to the reduction in transmission and distribution losses during that period of lower electric use. Simply stated there is less competition for T & D assets on the electric system during night time periods so the losses are lower and the resultant efficiency of the power that is delivered to the thermal storage cooling plants is greater.

A 53 page report (which can be provided upon request) prepared for the California Energy Commission (CEC) in the State of California in the United States highlights all three of these factors. From that report improvement in efficiency due to lower T & D losses can be set between 5% and 7%.

From this information and the CEC Report it can be seen that the improvement in energy efficiency that is attributable to the use of a district cooling system with thermal storage is at least 22%. The CEC Report set the improvement potential between 30% and 40% but the electric service areas under consideration in that document have a greater differential between daytime and night time ambient temperatures.

4) Environmental Benefits. Nitrous oxide and sulfur emissions from power generating plants are reduced as a result of the use of nighttime power to generate thermal storage. During the nighttime power plant efficiency is increased and losses in the electrical transmission grid and distribution systems are reduced. These factors combine to reduce burning of fossil fuels at power plant sites and crate the subsequent reduction in emissions resulting from the fossil fuel use.

5) Further Possible Cost reductions within the Customer Buildings. The 1.1°C chilled water provided by the External Melt Ice-based Thermal Storage technology can be used to reduce the air temperature supplied to the spaces within the buildings. The use lower air temperature reduces the air delivery requirement and as a direct result the size and cost of the ductwork needed to supply the air. The lower air delivery requirement also means that the electric energy required to run the fans will be dramatically reduced resulting in annual building operating cost savings.

II. In-Building Technology Innovations due to Ice-Based Thermal Storage Technology

General:

There are many different approaches in providing space air-conditioning. These approaches range from the basic individual self contained room air conditioners (window or through the wall type package air conditioning unit), to multi-zone roof top package air conditioning units, to the centrally supplied chilled water based system. Both the roof top unit and chilled water system are often equipped with certain terminal outlets for final space temperature control. The chilled water system has the additional flexibility of supporting either terminal fan-coil units working in conjunction with certain outside make-up air supply or with an all-air approach with properly proportioned mixed return and outside air delivering through various different final terminal control devices for final space temperature control. The delivering system has been continuously improving and becoming increasingly more sophisticated with electronic revolution and popularization.

While all different approaches have been steadily improving in terms of efficiency, economy and in sophistication, the chilled water based system delivery has been far more popular, especially in large facilities where self contained small units became impractical; too complex to maintain, too costly in operation and too difficult in accommodating any future space alterations and modifications. Therefore, for a building facility larger than 5,000 sq. meters, multi-zone chilled water based final comfort control all-air system has become the system of normal selection and choice.

The ultimate comfort of an interior space condition depends primarily on the satisfaction of four components; namely, the space temperature, relative humidity, air circulation and the cleanliness of air circulation in space. An all-air system is the best medium or vehicle to satisfy these four basic elements making up the ultimate comfort of a space. Any other terminal system unit approach may satisfy one or two of these, but not all four elements. This is the principal reason why an all-air system is the system of choice based on its simplicity in delivery, modification, system operation and maintenance. All-air systems are therefore used in most building types, especially in office and mix-use commercial complexes except for hotel rooms where the fan-coil units with make-up dehumidified outside air is usually the system of choice.

The traditional all-air system usually delivers its cooling capacity with the supply air temperature at 13.3°C (56°F) maintaining a space temperature at 24.4°C (76°F) and the relative humidity around 50%. This supply air temperature is usually selected as an optimum condition with consideration of delivery medium of air capacity and the physical building space required to house the supply air ductwork and possibly related heating and cooling supporting piping system.

"Cold" Air Secondary Space Cooling System:

The concept of direct use of the available low temperature chilled water in distribution and in producing low temperature supply air in secondary air distribution has opened the door for the concept of total integration in an ice storage based HVAC system design, which requires a total HVAC system consideration rather than single minded concentration in "load shifting" in a central plant.

Any supply air temperature between 4.4°C (40°F) to 10°C (50°F) can be considered "Cold" air because it is about 70% higher in temperature difference (Delta T) between the design room temperature and the normal supply air temperature. With a 70% higher delta T, the supply air capacity can be dropped by 40% as that illustrated below:

Supply Air Capacity in CFM = Room Sensible Heat/1.08*Delta T
SA1 = Supply air at 56°F (13.3°C)
SA2 = Supply air at 42°F (5.6°C)
Delta T1 = 76°F - 56°F =20°F
Delta T2 = 76°F - 42°F =34°F
SA2 / SA1 = (Room Sensible Heat/1.08* Delta T2) / (Room Sensible Heat/1.08* Delta T1)
= Delta T1 / Delta T2 = 20/34 =0.6 or 60%

This simple calculation is a part of routine work for an air-conditioning designer in order to arrive at the final air supply capacity for each individual space and accumulated with certain diversity or from a block area HVAC load to arrive at the final air-handling unit capacity. From this exercise, one can also readily see the large reduction in air capacity for a project in terms of air-handling units required and the primary ductwork running from each air-handling unit to the final zone control terminals. The associated electrical equipment and design original required can also be eliminated. A great deal of construction cost can be saved from these reductions. The similar reduction of chilled water piping material and associated control devices are also reduced.

Additionally, the architectural space required to house the HVAC system is also reduced. The impact of these reductions is quite large, if one knows how to take advantage of it. To make it easier to understand the situation, one may consider the original conventional design requiring ten air-handling units; it is now only requiring six. The impact is obvious and the reduction in cost is real. Additionally, the operating cost of the system is permanently reduced because the missing air-handling units were never there to consume the energy they otherwise would have.

The major benefit of the "Cold" air design approach is the ability to include a higher cost ice storage central plant with the overall cost of HVAC system remaining essentially the same, as long as the basic system quality is a good one and an all-air system is included in the final delivery of space conditioning. The projects designed with the "Cold" air design approach include Office Buildings, Schools, Hospitals, Laboratories, Airports and many large high-rise mixed-use commercial complexes. With an Ice-Based Thermal Storage District Cooling Plant supplying low temperature chilled water of 1.1°C; any building connected to the system should be able to save on the initial investment between 35 to 50% from both the elimination of in-building central plant and the air side system installation reductions. The benefit of elimination of central plant in building will provide more space for the primary purposes of the building with additional benefit of not requiring long term operational engineering staff.

Summary of the Impacts of Ice-Based Thermal Storage on District Cooling Plant Technology

External Melt Ice-Based Thermal Storage technology applied to a district cooling plant will cost more in the mechanical systems than all-electric chiller technology. If that is where the cost impact stopped few developers would choose to use the storage technology over the all-electric chiller technology.

The fact is that the 1.1°C supply water and the electric load leveling features of the storage technology positively impact the entire pipe distribution system, the heat exchangers, the air handling and air distribution equipment, and finally the power generation, transmission and distribution facilities.

When an integrated design approach is used for plant, distribution, building interface, and power supply, the full benefits of the features of Ice-Based Thermal Storage technology can be realized. When that is done, the cost of the entire development is reduced when External Melt Ice-Based Thermal Storage technology is used.