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District Cooling Design Guideline

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1.0 PURPOSE

The purpose of this document is to provide the Entity the guidelines for designing and implementing the District Cooling System (DCS) compliance to the resolution No. 3 passed by the Saudi Council of Ministers dated 2/1/1438 (H) which mandates the use of District Cooling for new large development projects requiring a centralized cooling system. The document discusses not only energy savings related techniques but also ways to reduce the cost and improve recovery of investment in providing the District Cooling System.

2.0 SCOPE

This document is issued for reference purpose only to guide DCS Designers in the development of energy efficient and cost optimized design.

The document also covers operational techniques to increase equipment and system operating efficiencies and reliability in relation to document EPM-KE0-GL-000004, Improving Energy and Water Consumption in Existing and New Buildings.

Notwithstanding the recommendations presented in this document, the final responsibilities for the efficient design of HVAC system shall remain with the Entity and /or A/E.

3.0 DEFINITIONS

Abbreviations	Description
ASHRAE	American Society of Heating, Refrigerating, and Air-conditioning Engineers
A/E	Architect/Engineer
COP	Coefficient of Performance
DCS	District Cooling System
DRV	Double Regulating Valve
EER	Energy Efficiency Ratio
FSD	Fixed Speed Drive
HVAC	Heating, Ventilation, and Air Conditioning
IPLV / NPLV	Integrated Part Load Value / Non-Integrated Part Load Value
I&C	Instrumentation and Control
LSG	Light to Solar Heat Gain Ratio
PICV	Pressure Independent Control Valve
RH	Relative Humidity
ROI	Return of Investment
SH	Shading Coefficient
SHGC	Solar Heat Gain Coefficient
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

4.0 REFERENCES

1. EPM-KEM-GL-000001 - Mechanical Design Guideline
2. EPM-KEM-GL-000004 - Improving Energy and Water Consumption in Existing and New Buildings
3. EPM-KE0-GL-000016 - General Design Guideline
4. ASHRAE District Cooling Guide, 2013 with 2016 errata

5.0 RESPONSIBILITIES

This document will be owned and maintained by Mashroat Engineering. Entities are responsible to provide this guideline to A/E's responsible for the design of the DCS.

6.0 PROCESS

6.1 Introduction

District cooling systems are getting popular nowadays due to the multiple benefits that can be obtained from using these systems compared to building chilled water systems. Benefits can range from energy savings (through evaporative cooling via closed or open cooling towers required for Centrifugal Chillers, and series-series counter flow evaporator and condenser arrangement), maintenance cost savings, simplicity of maintenance, environmental benefits, and building space savings for cooling equipment which can be turned into revenue. The only disadvantage of a District Cooling System is that the capital cost is highly expensive compared to that of the combined individual building chilled water systems per ton of refrigeration.

This document focuses on five (5) topics as exceptions to the general guidelines for sizing equipment, components, and piping which are as follows;

1. Requirements for District Cooling System (DCS) implementation shall be discussed to have a justifiable duration for the Return of Investment (ROI) since the piping distribution and associated equipment is extremely expensive .
2. The source of energy savings for DCS compared to the building chilled water system.
3. Energy saving techniques will be discussed in relation to document EPM-KE0-GL-000004, "*Improving Energy and Water Consumption in Existing and New Buildings*" to optimize power consumption of the equipment and system, as well as the implications of that technique.
4. Points to consider in designing DCS which defines what chiller type and piping distribution will be most applicable based on site conditions.
5. The regulatory requirements for implementing DCS in KSA.

6.2 Guidelines for Equipment, Components, and Distribution Pipe Sizing

1. Refer to document EPM-KEM-GL-000001 section 4.2.7 for Hydronic Cooling System.
2. Refer to document EPM-KEM-GL-000001 section 4.2.8 for Condenser Water System.
3. Refer to document EPM-KEM-GL-000001 section 4.2.13 for Building Automation System.
4. Refer to document EPM-KEM-GL-000001 section 4.3.3 for Cooling Equipment and Accessories.
5. Refer to document EPM-KEM-GL-000001 section 4.3.4 for Common System Components

6.3 Requirement for Lower Capital and Faster Recovery of Investment

As all District Cooling Providers and Owners are aware of the high capital investment required to implement the District Cooling System, some parameters are set by the Standards to ensure modest duration for the return of investment when compared to building chilled water systems. In general, buildings that are supplied with chilled water from the District Cooling must have high cooling utilization. ASHRAE HVAC System and Equipment Standard requires high annual cooling load factor and high thermal load density for immediate Return of Investment (ROI). Applicability of DCS is best suited for industrial complexes, highly dense urban areas composed of high rise buildings, airports, etc.

One major technique to reduce the over-all capital cost is to use wider delta T for the chilled water design. Wider delta T significantly reduces pipe size, pump capacity, and the size of thermal storage tanks. Ideal chilled water supply temperature of 3.9°C is recommended to avoid problems associated with water expansion at lower temperatures, and return temperature can be as high as 15°C for non-critical %RH application.
Excessive estimate of cooling loads is a common problem in District Cooling System which results in oversized equipment and system. The oversizing of system and components is one major reason for high capital investments. During the planning stage, it is difficult or almost impossible to attain the exact cooling requirements since details of building construction, occupancy, time of usage, HVAC air distribution, energy recovery, and other specific information cannot be defined. This is one major advantage of using a building chilled water system where the cooling load can be accurately accounted during design, thus saving major equipment and piping distribution cost. HVAC designers consider worst case scenarios during the planning phase to estimate cooling loads due to the reasons stated above, therefore DCS Providers and Owners are advised to implement building design criteria standardization to guide HVAC designers and reduce variations

in cooling load estimates. The following are major HVAC design criteria which greatly affect variation in cooling estimates that are required to be standardized for buildings served by DCS:

1. Use of double walls with insulations using specific characteristics.
2. Amount of fenestration (amount of glass such as windows and other openings)
3. Construction of roof slab
4. Use of high U-value, lower SHGC (Solar Heat Gain Coefficient), higher SC (Shading Coefficient), and higher LSG (Light to Solar Heat Gain Ratio) for glass.
5. Use of energy recovery
6. Requirement of building pressurization or implementation of building envelope air leak testing to reduce infiltration.
7. Diversity factors - shall be thoroughly assessed.

6.4 Source of Energy Savings for District Cooling System compare to Building Chilled Water System

District Cooling System has been strongly commercialized to save from 30% to 40% of the building energy when compared to the summation of individual building chilled water systems and/or other smaller direct expansion systems. Many aspects of District Cooling System is similar to building chilled water system design since the majority of the design techniques to reduce energy consumption can be used on both system. The only advantage of DCS compared to an individual building chilled water system in relation to energy savings, is the use of double-effect absorption chillers utilizing waste heat from power generating plants (or any other heat source) and the series-series counter flow arrangement of the chiller evaporators and condensers which is used for large chilled water systems. Series-series counter flow configuration of Centrifugal Chillers has been traditionally used for large chilled water systems and large chillers, and proven to save considerable amount of energy. Utilization of ammonia chillers (with or without cooling towers, if permitted by local regulations), centrifugal chillers with cooling towers, heat recovery chillers, thermal storage, free-cooling chillers and economizers can be applied for both large and smaller systems.

In the older days, use of large Centrifugal Chillers opened the way for preferring DCS over multiple smaller chilled water systems because the full-load and part-load efficiencies are much better than the building chilled water system’s smaller chillers of different compressor types. Use of Centrifugal Chillers nowadays are not only limited to larger systems but there are Centrifugal Chillers available in the market down to 200 tons with the same efficiency as in the larger units in part and full load. Compared to other types of chillers with the exception of Ammonia Chillers using water cooled condenser, Fixed Drive Centrifugal Chillers offer the highest EER or COP at full load, which means that lower electrical power is required per nominal tons with smaller equipment footprints at full load. Ammonia chillers on the other hand have the advantage over Centrifugal Chillers since they can operate with air-cooled condensers especially when there is a scarcity or unavailability of cheap water for condenser cooling required for Centrifugal Chillers. The major advantage of a Centrifugal Chiller over a fixed speed drive Ammonia Chiller is higher efficiency at part load which can go as low as 0.2 Kw/ ton IPLV, unlike FSD ammonia chillers where efficiency is almost constant from full-load to part load (VSD Ammonia Screw Chiller has better efficiency at part-load compared to FSD). It is therefore important to know the concept and intent in designing DCS to optimize energy using different types of chillers and utilizing waste heat source.

The comparison of DCS to a building chilled water system must be based on the same design footprint as most DCS are using Centrifugal Chillers which require a cooling tower for condenser heat rejection and should not be compared with air cooled chillers. Condenser evaporative cooling is the major reason for energy reduction in DCS and not the system itself.

6.5 Energy Optimization Technique

The following are the techniques that can be used to improve and optimize the power consumption of a DCS in relation to its circuit only (air side energy optimization technique and consumer chilled water circuits are not included), which are explained in detail in document EPM-KE0-GL-000004, “*Improving Energy and Water Consumption in Existing and New Buildings*”:

1. Use of Pressure Independent Control Valves to resolve problems related to low delta T

2. Use of multiple Differential Pressure Sensors in prospective indexes and providing the optimum Setting
3. Implementing Variable Primary Chilled Water System only instead of Primary/Secondary System
4. Properly segregating circuits
5. Shared loading against single equipment loading in part load for VFD driven pumps
6. Combining fixed speed chillers, variable speed chillers, large capacity, and small capacity chillers
7. Increasing chilled water and condenser water delta T
8. Chiller and cooling tower energy balance
9. Use of Free-Cooling Chillers
10. Use of Heat Recovery Chillers
11. Use of Double-effect Absorption Chillers
12. Use of Ammonia Chillers
13. Use of evaporative cooling for closed and open condenser water systems
14. Use of Thermal Storage System, Ice Storage and Chilled Water Storage System
15. Use of Water Side Economizer
16. Selecting the proper head for pumps
17. Building Automation System controls optimization
18. Implementation of proper Testing and Commissioning
19. Post-Occupancy Commissioning
20. Other energy saving techniques as noted in the referenced document

6.6 DCS - Key Design Considerations

When designing a DCS System, the following important points should be considered:

1. To optimize the energy consumption, the fixed speed centrifugal chillers should be used instead of VFD chillers since full load efficiency is higher. DCS should be designed to ensure that each chiller will run at 100% of its design capacity at high and low cooling demand by utilizing a Thermal Storage System. Thermal Storage System increases the system cooling efficiency especially when cooling loads are shifted at night when condensing temperature is lower, thus results in chiller higher operating efficiency. When Thermal Storage is not implemented for any reasons (such as financial limitations, although this is not recommended), the designer should study the possibility of mixing VFD chillers with fixed speed drive chillers to improve the efficiency of the secondary chiller at part load. The HVAC designer should also provide operational sequence for the combination to optimized energy consumption.

   When utilizing a Thermal Storage System, the HVAC designer must consider the over-all expected thermal load profile using HVAC cooling load software. Factors affecting the thermal load profile shall be properly assessed such as timing of lighting, occupancy, and process loads variations. Cooling load software must have a built-in ambient hourly climatic profile so that the load profile can be accurately assessed. The capacity of the Thermal Storage System must be based on the following conditions to ascertain economical and effective usage;

   a. Variation of the peak instantaneous hourly cooling load profile from the average cooling load during the day of peak cooling requirement; and
   b. With consideration of utilizing the Thermal Storage System during the day to reduce number of chillers required for cooling as well as the capacity of the building electrical power utility. Thermal Storage Tank shall be designed in parallel and stratified to maximized thermocline resulting in accurate supply and return temperature of the chilled water system.

   Option of locating energy storage at the chiller plant or remotely shall be assessed by the designer. Energy storage could be at grade or underground. There are advantages to different location choices, depending on the type of storage technology that is being used. This is discussed in

Chapter 6 of the ASHRAE District Cooling Guideline. The DCS designer should justify not only the choice of energy storage technology, but also the decision of where to locate it within the system.

2. Use of Series-series counter-flow chillers arrangement (for the evaporator and condenser) shall be considered for energy optimization. Series-series counter flow arrangement reduces system power consumption by 8% to 12% compared to parallel-parallel chiller arrangement, and 4% to 6% savings compared to series (evaporator)-parallel (condenser) arrangement. Increase in chillers efficiency due to lower lifts over runs (1) decrease of chiller efficiency due to the use of single stage evaporator and (2) the increase in pump head required to overcome the combined pressure loss of both chiller evaporator and condenser. A DCS System design where chillers are set in a parallel configuration has no energy savings benefits when compared to the summation of individual building chilled water systems power consumptions. The worst option is when a Primary-secondary system is utilized when the chillers are capable of running in Primary-only distribution, which will result in increased power consumption.

   Series chiller evaporator arrangements are used for preferential loading of the first chiller ensuring that it runs at 100% of its capacity. Combined efficiency of both chillers when one is at full load and the other at part load is higher compared to when both chillers are in part load.

   The DCS Designer shall provide an operational sequence for the series-series counter flow considering operation, optimization of energy consumption, and operational safety. The selected chiller manufacturer shall further enhance the designer’s intent for the sequence of operation and deliver, and install a pre-programmed DCS controllers.

3. Ammonia chillers should be considered to be used in DCS by the designer when local regulations and budget permits. Ammonia is better in efficiency both for air-cooled and water-cooled condenser systems compared to other refrigerants. Ammonia is a natural refrigerant, cheap, and has zero global warming potential and ozone depletion. Implementation of safety measures such as ammonia leak detection system and exhaust system to ensure safe use of the refrigerant for the central plant is encourage.

   For hot and humid locations where cooling towers are not suitable for use because the prevailing wet-bulb temperature is high throughout the year (e.g., projects close to the sea) air-cooled condenser ammonia chiller can be the best option. Hot and humid climate results in large cooling towers and inefficient operation of both the tower and chiller. The designer shall assess the overall system efficiency for the system recommended for this climate.

4. DCS design should consider operation of the system at the early phase of any urban development as the cooling load will be lower. Use of Thermal Storage is highly recommended.

5. For dry locations (such as Riyadh) where wet-bulb temperature is very low for most of the year, the use of Free-cooling chillers with economizer shall be considered since condenser water temperature from the cooling tower can be way below 13°C, especially in mid-summer and mid-winter season. This will reduce the cooling load imposed on the chillers by pre-cooling the return chilled water from the buildings.

6. When implementing reset control based either on ambient temperature or chilled water return, the design must be coordinated with building HVAC designers so that the design criteria can be adjusted for critical %RH application (such as hospitals, medicine factories, pharmaceuticals, printing factories, etc.) specially for projects located in humid climates. Effect of reset control is much less of a concern in low humidity locations such as Riyadh.

7. Use of a PICV is strongly advised in lieu of conventional 2-way control valve. This is to resolve issues with low delta T associated with the 2-way conventional control valves which results in tremendous waste of energy. Refer to document EPM-KE0-GL-000004, “*Improving Energy and Water Consumption in Existing and New Buildings*” for other benefits of using a PICV in lieu of conventional control valves. PICV is the most suitable valve for DCS systems since it is an automatic balancing valve. DRV is not advisable since each time a building is added to the DCS, balancing works must always be repeated.

8. The Designer is to consider the requirements for the accurate measurement of flow, temperature and pressure at each building interface (both supply and return) not only for the purpose of monitoring the individual building usage but also for trouble shooting of any problem in the network during O&M. Refer to ASHRAE District Cooling Guide 2013 for the specific recommendations on the type of instrumentation and accuracy that should be provided to measure these variables.

9. The Designer is to consider all aspects of the project and select appropriate I&C technology that serves the purpose best and provide justification for the selection of I&C technology. Refer to Chapter 7 of the ASHRAE District Cooling Guide 2013 for the guideline on the selection of appropriate instrumentation and control system (BMS versus SCADA).
10. For systems with long runs of underground piping it is often desirable to oversize the piping slightly to not only reduce pumping costs, but also to facilitate future growth. This should be evaluated by the designer. Pipe stress analysis should be conducted to identify requirement for fixed supports and expansion points in order to reduce or eliminate stress in piping due to contraction/expansion. Required number of manholes for valve boxes and expansion joints shall be provided to facilitate the inspection and maintenance of the underground piping.
11. Insulation shall be designed in such a way to reduce heat gains. Insulation properties and thickness shall be provided to have 1°C gain from and back to the chiller to maximize cooling coil delta T. A leak detection system shall be provided in buried piping for ease of identification in case of pipe leakage or failure of insulation. The leak detection panel shall be located in Central Plant and shall be connected to the BMS or SCADA for automatic notification.
12. Water chemistry/quality control shall be assured during the commissioning stage. A water specialist service shall be employed to check and verify that the chilled water quality conforms to pertinent standards requirements (pH, conductivity, total hardness, alkalinity, chlorides, soluble iron, etc.). Use of atmospheric or vacuum de-aeration is recommended to eliminate air (which contains oxygen and CO2) dissolved in water which is the main factor for internal pipe corrosion. Appropriate corrosion inhibitor shall be provided through automatic chemical dosing system. If cooling towers are used, ASHRAE recommends: reducing exposure of wetted surfaces to direct sunlight to minimize biological growth, design for optimized cycles of concentration based on make-up water chemistry and evaporation rates, proper pH control, selection of materials to minimize biological growth based on makeup water chemistry, and provision of features to facilitate inspection and manual cleaning.
13. DCS connection to the buildings shall be through a plate heat exchanger with 0.5°C approach. This will result in lower building chilled water supply resulting in effective cooling coil dehumidification and lower supply air flowrate. Direct connection is not recommended due to the problems of assuring water chemistry/quality control on each building during the commissioning and O&M stage.
14. When Cooling Towers are used, the basin shall be self-cleaning type and side stream filtration shall be provided in the condenser piping for the automatic removal of sand and dirt. Cooling towers shall be provided with near square water discharge pattern spray nozzle to increase the thermal and mass heat exchange.

6.7 REGULATORY REQUIREMENTS

1. For other technical and regulatory requirements such as permits, licenses, criteria for implementation, and tariffs, the entity is referred to ECRA (Electricity and Cogeneration Regulatory Authority) document ERD-TA-010 – District Cooling Regulatory Framework.

2. Reference to the resolution No. 3 passed by the Saudi Council of Ministers dated 2/1/1438 (H), additional requirements for the implementation of DCS shall include:
   a. It must be a new project
   b. The demand for cooling exceeds 15,000 Tons
   c. The area in which the project is to be constructed is highly dense (a construction factor of more than 1.5, of which the total build-up area for its total land area.
   d. That sufficient quantities of treated water are available in the area in which they are located.

   For residential areas composed of villas or mixed use application where the majority of use is for residential (villas) purpose, it is highly recommended that a life-cycle cost study be conducted to ensure proper appropriation of funds with respect to ROI when using DCS compared to other mechanical cooling systems.

7.0 ATTACHMENT

1. EPM-KEM-TP-000027 - District Cooling System Design Optimization Checklist

Attachment 1 - EPM-KEM-TP-000027 - District Cooling System Design Optimization Checklist

PROJECT NAME:		DRAWING NO.	REV.	

No.	INSPECTION ITEM	CHECKED SATISFACTORY N/A	YES	NO
1	Pressure Independent Control Valve to be use instead of conventional type.	☐	☐	☐
2	Chiller evaporators and condensers are arranged in series-series configuration.	☐	☐	☐
3	Demand for cooling exceeds 15,000 Tons as per ECRA Regulation ERD-TA-010 (District Cooling Regulatory Framework). Other requirements in the document shall also be applied prior to the implementation of DCS.	☐	☐	☐
4	For projects located in low wet bulb temperature region, use of Free-cooling chillers with economizer specified.	☐	☐	☐
5	As local regulation permits, Ammonia type chiller (either water cooled or air cooled) specified to reduce over-all power consumption especially in projects located in high wet-bulb temperature region where centrifugal chillers and cooling towers are very inefficient.	☐	☐	☐
6	Thermal Storage Tank included in the design of DCS	☐	☐	☐
7	Thermal Storage Tanks are design in parallel and stratified to optimize thermocline	☐	☐	☐
8	Thermal Storage Tank type and location is considered based on the technology used. Location of project is also considered if there are potential for tank floatation in case of below grade installation.	☐	☐	☐
9	DCS design provides operational sequence which states strategies for energy optimization as per Mashroat document EPM-KE0-GL-000004.	☐	☐	☐
10	Delta T for chilled water supply and return maximized to reduce distribution pipe sizing and Thermal Storage Tank capacity. Delta T is in the range of 9° to 10°C, or higher.	☐	☐	☐
11	DCS chiller controllers are manufacturer pre-programmed and pre-configure controllers intended for DCS application.	☐	☐	☐
12	Fluid design velocity maximized to reduce distribution pipe size?	☐	☐	☐
13	Standardization of building construction (for façade and roof), amount of fenestration, glazing characteristics, use of energy recovery, and building pressurization are implemented to limit variation in cooling load estimates.	☐	☐	☐
14	The project development has high annual cooling load factor and high thermal load density for immediate Return of Investment (ROI).	☐	☐	☐
15	When centrifugal chillers are used, sufficient supply of TSE (Treated Sewer Effluent) is available for Cooling Tower. TSE quality shall comply to ECRA Regulation ERD-TA-010 (District Cooling Regulatory Framework)	☐	☐	☐
16	Specification requires the highest COP (or EER) and IPLV/NPLV for chillers	☐	☐	☐
17	Specification requires the highest combined efficiency for pumps and motor			
18	Chiller motor has high voltage power supply to reduce winding losses	☐	☐	☐
19	Cooling tower and chiller energy balance study has been conducted to determine best delta T for condenser water to increase chiller-CT combined efficiency.	☐	☐	☐
20	DCS uses primary chilled water distribution rather than primary-secondary to reduce capital investment and power consumption.	☐	☐	☐
21	DCS plant is strategically located to reduce run of distribution piping thereby reducing friction head.	☐	☐	☐
22	Substantial insulation thickness provided to reduce distribution piping heat gain and maximized cooling coil delta T.	☐	☐	☐
23	Contraction/expansion joints and pipe anchors provided as per the Pipe Stress Analysis result to eliminate excessive stress in piping.	☐	☐	☐
24	Sufficient depth for burial of distribution piping considered in the design.	☐	☐	☐
25	Pro and cons on the type of Instrumentation and control considered between SCADA and BMS. Client to assess priority of importance to decide which system to be used.	☐	☐	☐
26	DCS is designed for indirect connection to eliminate possible contamination of the system during each building commissioning and during O&M. HEx is designed for minimum approach (0.5 °C).	☐	☐	☐
27	Use of atmospheric or vacuum deaerator considered in design for the closed loop.	☐	☐	☐

28	Source of flushing water and discharge point of contaminated waste water considered during design to comply with COSHH.	☐	☐	☐
29	Chemical dozing pot included for close distribution piping system flushing. Dozing pot connected between supply and return of the distribution pump.			
30	Specification indicates required water chemistry (pH, conductivity, total hardness, alkalinity, chlorides, soluble iron, etc.)	☐	☐	☐
31	Field device required accuracy and drift specified by the designer.	☐	☐	☐
32	Closed evaporative cooling tower used for project located in dusty/sandy environment	☐	☐	☐
33	Cooling towers was designed with self- cleaning basin. Side stream filtration provided in the condenser water piping for automatic removal of sand and dirt.	☐	☐	☐
34	Cooling towers are located to have shading and not exposed to direct sunlight for minimizing biological growth.	☐	☐	☐
35	Chilled water circuits, condenser water circuits, process water circuits (for closed cooling tower) provided with automatic chemical dosing system for water chemistry/quality maintenance.	☐	☐	☐
36	Btu-meter interface with building chilled water system inclusive of PLC and fiber optic cable (including roughing-ins and field devices) ownership clearly identified in the drawings, specifications, and contract. Interface shall be closely coordinated between providers and end-users.	☐	☐	☐

No.	Reviewer's Comments	Resolution
Originator's Name / Signature and Date:		Checker's Name / Signature and Date: