Design limitations that can justify the use of enhanced Ice-based Thermal Storage systems

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DISTRICT COOLING DESIGN LIMITS

CONSIDERATIONS THAT CAN LIMIT DESIGN

1. Spatial and Functional
   a. Energy source availability and sufficiency
   b. Availability of other resources (water, drainage, etc.)
   c. Plant location driven
   d. Design Working Pressure of Piping Systems
   e. Distribution Piping System fluid velocity-density

2. Cost Driven Factors
   a. Land size
   b. Building configuration (# of Floors, Roof size, column spacing, FL-FL height)
   c. Technology selection
   d. Number and capacity of individual chilling units (Unit cost, electric service)

3. Environmental / Regulatory
   a. Refrigerant Selection
   b. Efficiency standards
   c. Sound limits

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DISTRICT COOLING DESIGN LIMITS

USING KAU CUP-2 AS A LOCAL EXAMPLE

Energy source availability and sufficiency:

Electric power was available from the local utility but there were limits on the maximum commitment. A profile of the peak day cooling load and electric use is presented on the page 4 slide. This shows that using a cool storage system would allow approximately 15 MW to be eliminated for the CUP-2 electric service.

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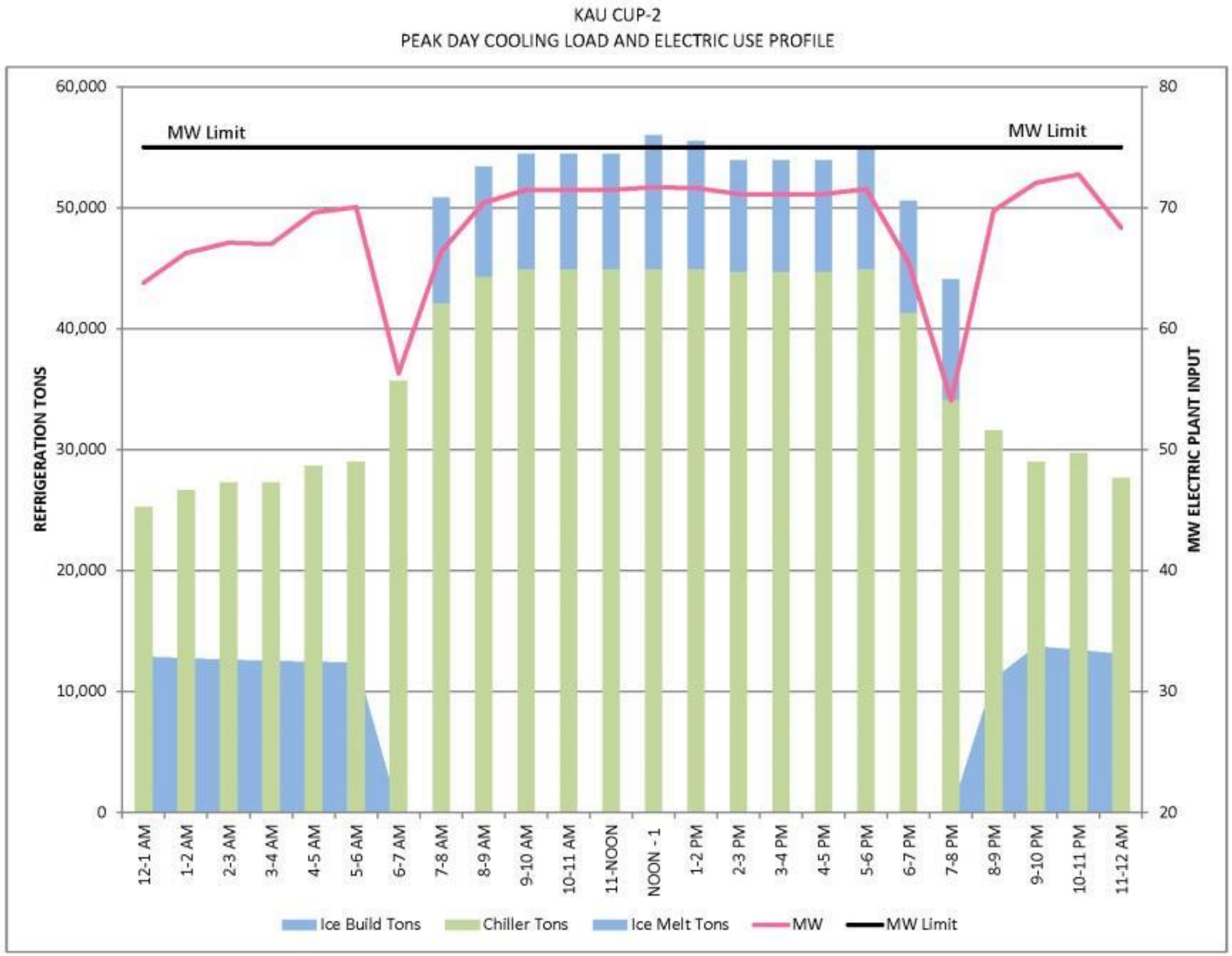
DISTRICT COOLING DESIGN LIMITS



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DISTRICT COOLING DESIGN LIMITS

USING KAU CUP-2 AS A LOCAL EXAMPLE

Availability of other resources (water, drainage, etc.):

A reliable source of water could not be established. This was not only true when design started in 2001 but it continues to be a fact. Since water was not available, air-cooled radiators had to be used to reject the heat from the chilling units. Due to the high ambient temperatures in Jeddah air cooled radiators require a minimum of 0.16 square meters of area at grade level for each ton of plant chilling capacity. This is slightly greater than the ground floor space required for all chiller units and related pumps and other plant equipment. A fraction of the air-cooled radiators required for CUP-2 are shown on slide 6.

DISTRICT COOLING DESIGN LIMITS

Less than 50% of the required air-cooled radiators

DISTRICT COOLING DESIGN LIMITS

USING KAU CUP-2 AS A LOCAL EXAMPLE

Design Working Pressure of Piping Systems:

Sizing the piping for the distribution system must consider the cooling load and location of the customer buildings relative to the location of the cooling plants, as well as the general layout of the piping. One reason for this is to make certain that pressure of the water in any section of pipe, that is required to serve some number of buildings, does not exceed the design working pressure of that system, usually 150 PSI (1034 kPa).

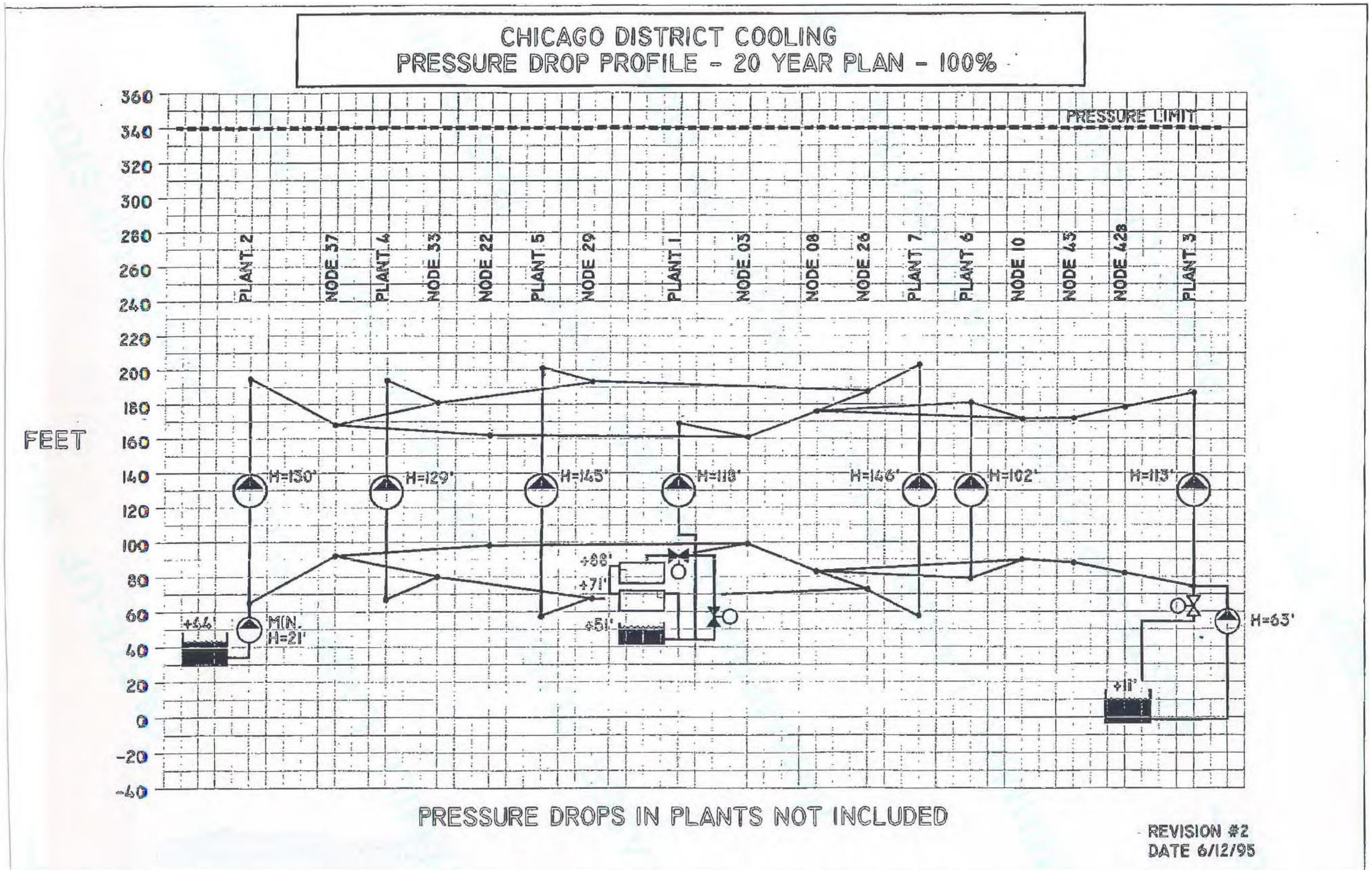
The graphic on slide # 8 depicts the considerations that should be understood.

Delivering the cooling load at a larger temperature differential, by lowering the supply temperature, is a tool that a designer has to reduce system flow rate, which has a positive affect upon the pipe sizing and pressurization requirements.

DISTRICT COOLING DESIGN LIMITS

USING KAU CUP-2 AS A LOCAL EXAMPLE

Design Working Pressure of Piping Systems:



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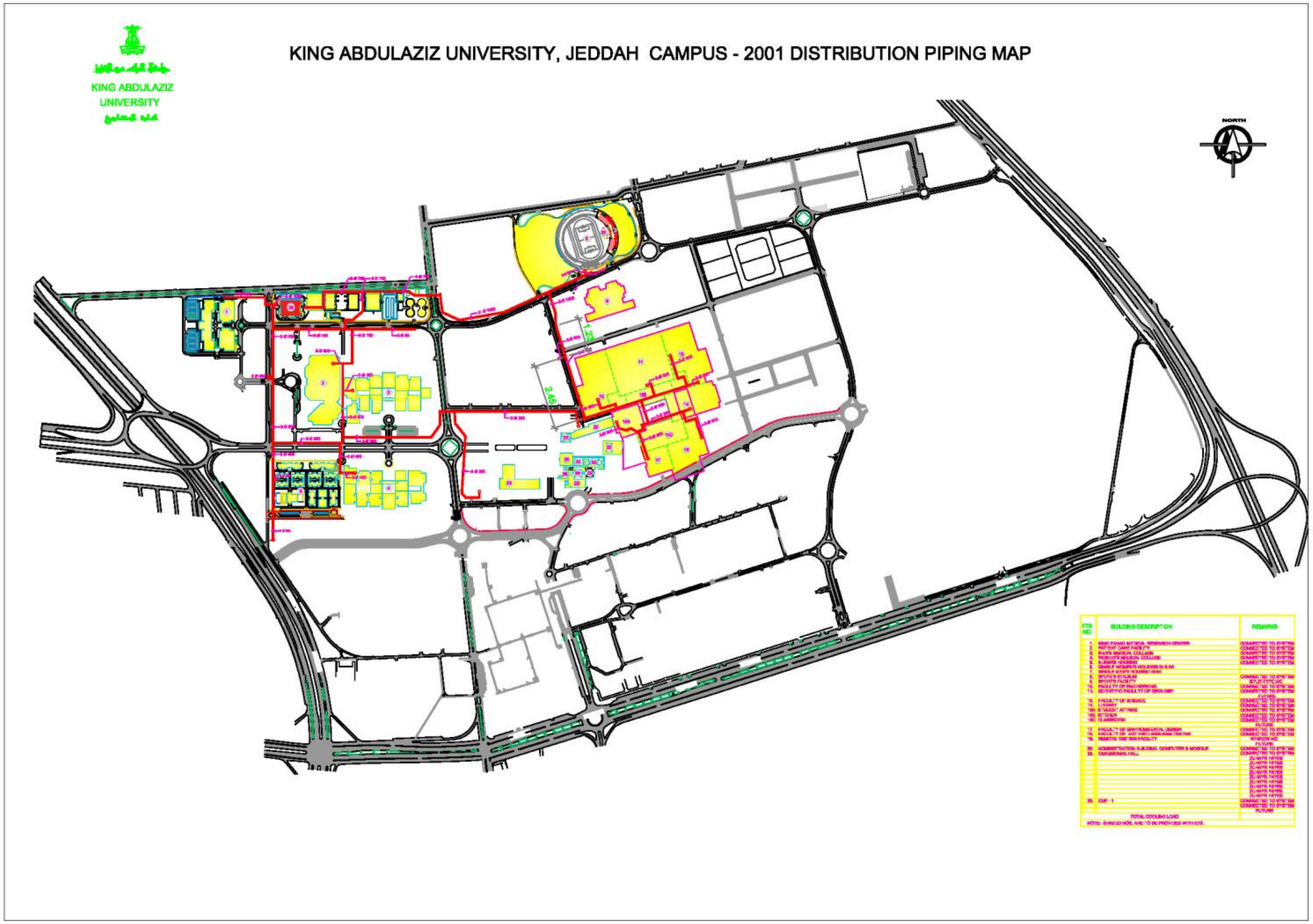
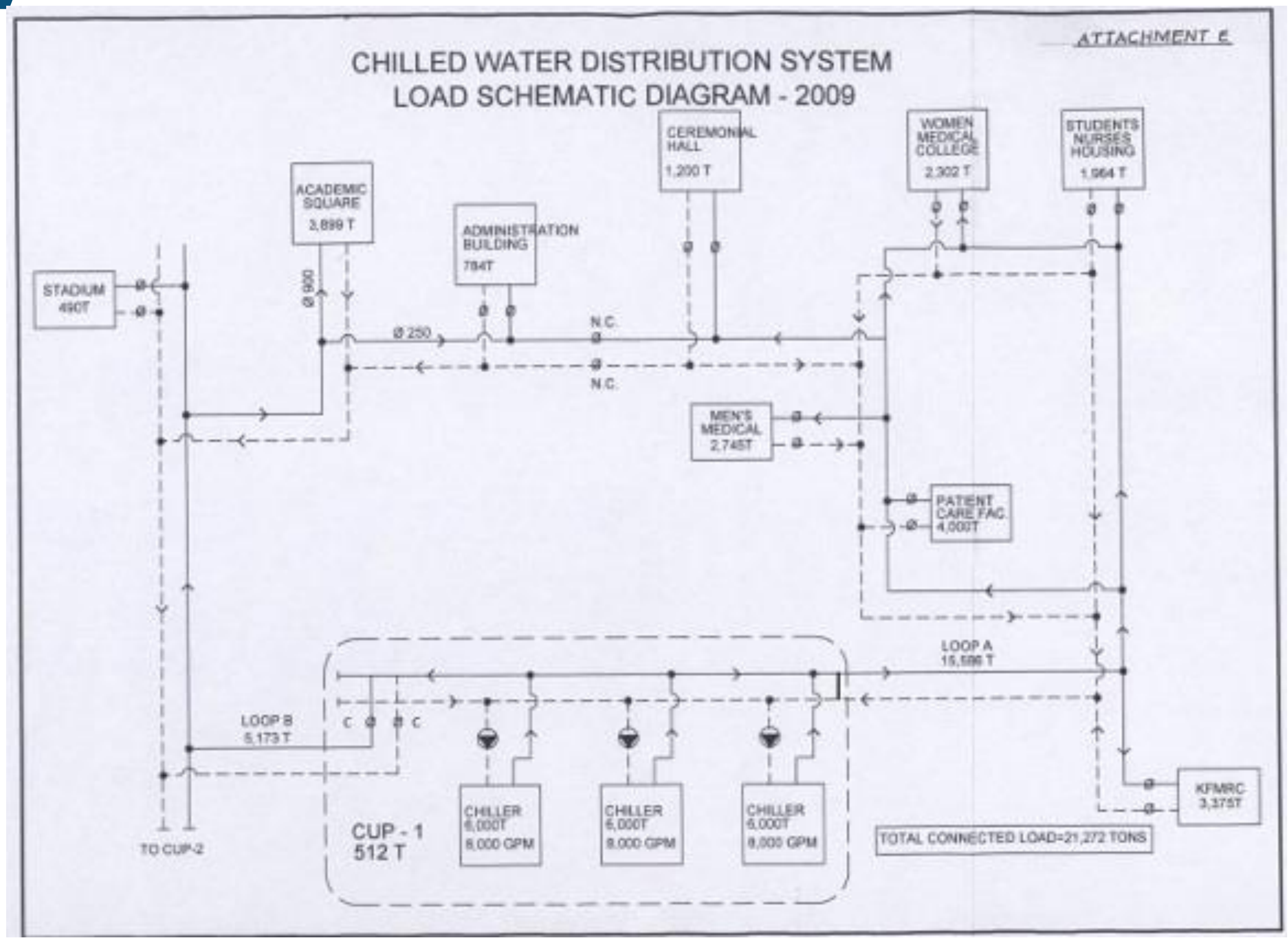
KAU 2001 CAMPUS MAP – 13,000RT



KAU 1996 to 2015 DISTRIBUTION SYSTEM



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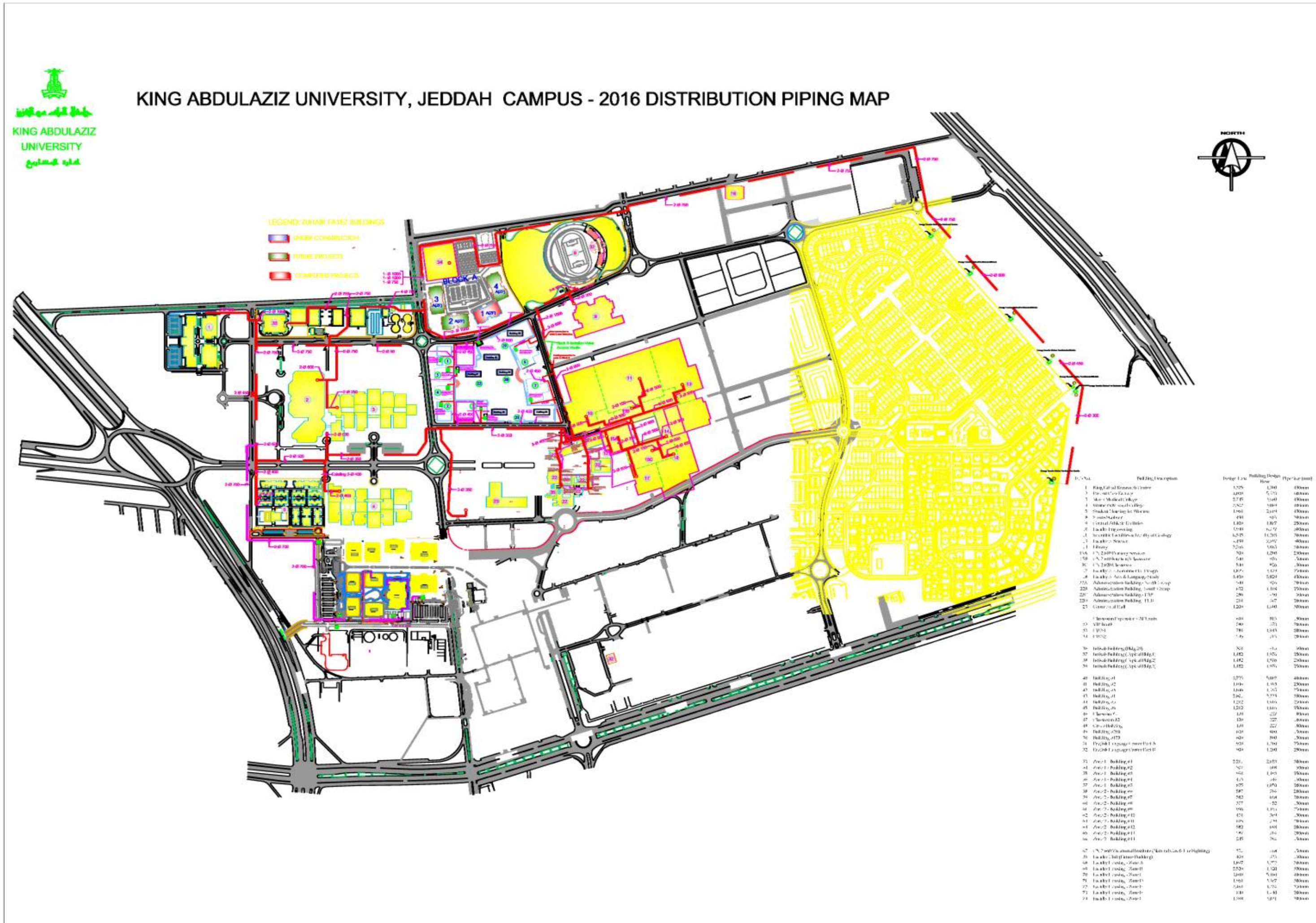
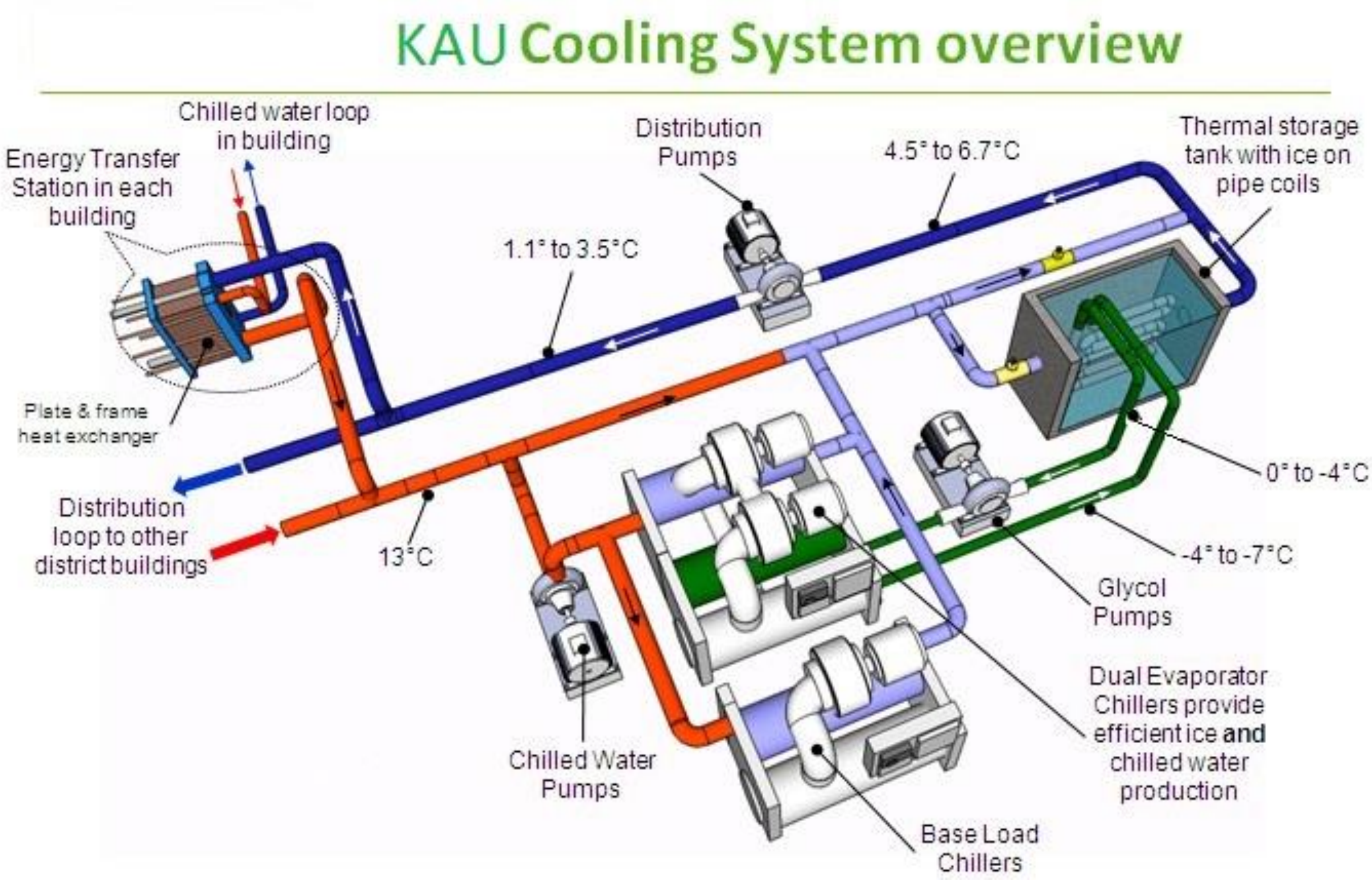
KAU 2016 CAMPUS MAP – 86,000 RT



KAU CUP-2



KAU Cooling System overview
Chilled water loop in building
Energy Transfer Station in each building
Distribution Pumps
4.5° to 6.7°C
Thermal storage tank with ice on pipe coils
1.1° to 3.5°C
Plate & frame heat exchanger
0° to -4°C
Distribution loop to other district buildings
13°C
-4° to -7°C
Glycol Pumps
Dual Evaporator Chillers provide efficient ice and chilled water production
Chilled Water Pumps
Base Load Chillers

KAU CUP-2 Ice-Based Thermal storage

One of six compartments of galvanized pipe coils used to generate and store 126,720 ton-hours of thermal energy. Total construction volume = 7.4 ton-hours per m³.

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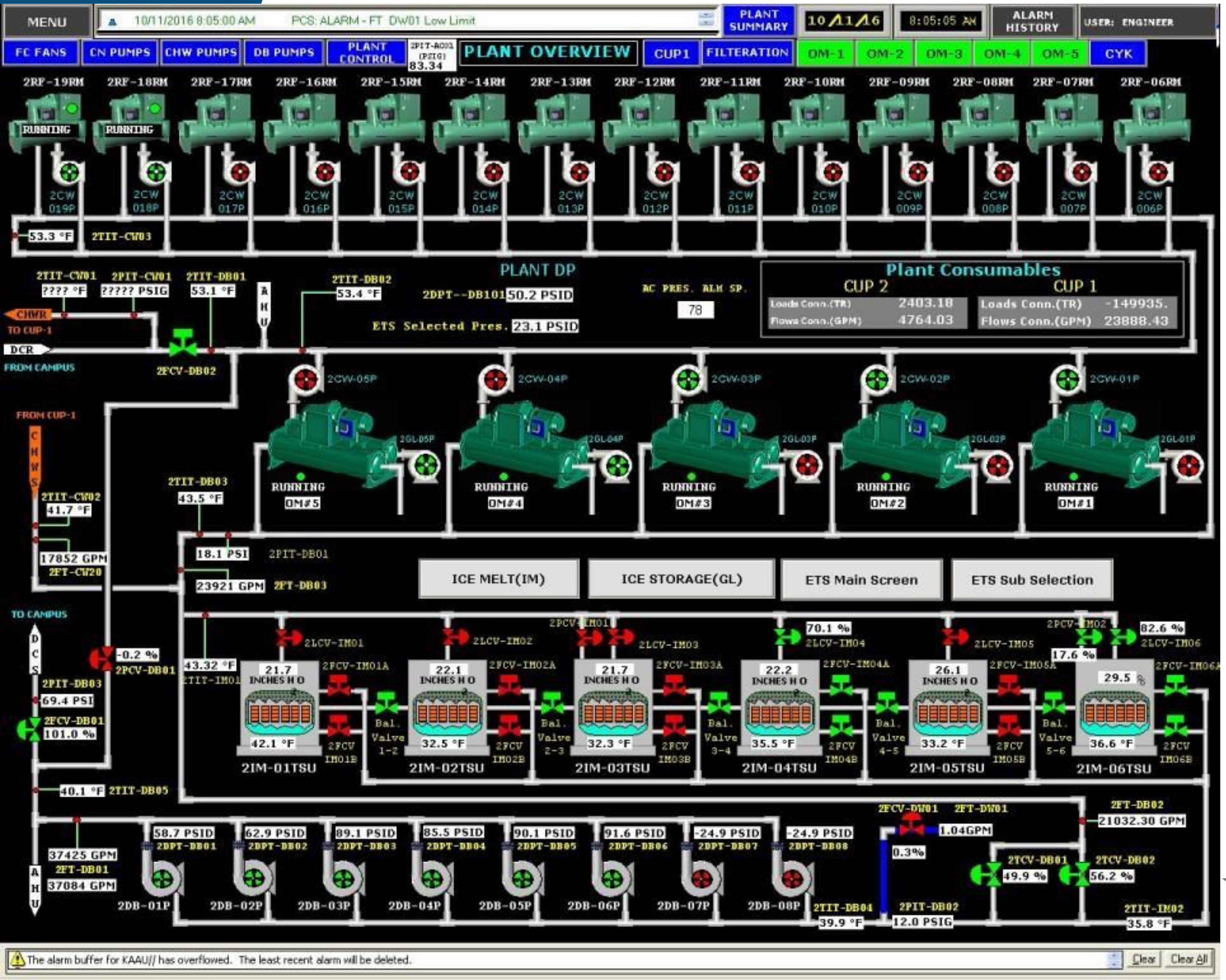
KAU CUP-2 Primary Control Screen



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KAU CUP-2 Automation System

The plant automation system features adaptive control algorithms that optimize

1. The use of thermal storage each day, and

2. Distribution pump sequences that allow reliable and effective control of 2 variable speed pumps in parallel with 6 constant speed pumps.

3. Uses the relatively high daily range in dry bulb temperature to generate ice-based thermal storage during the nighttime hours.

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KAU CUP-2 Automation System

Inputs to Thermal Storage System Control Algorithms		
Cooling Load Inputs	**Chiller System Input**	**Storage System Input**
Current instantaneous cooling load	Number and capacity of available chiller units	Installed Thermal Storage Inventory (Ton-hours)
The average cooling load over the past 2 hour time period	Current instantaneous water chilling output from CUP-1	Storage Inventory at 7am this day (Ton-hours)
Time of day	Current instantaneous water chilling output from CUP-2	Current Storage Inventory in (Ton-hours)
Outside air temperature		Current Storage Inventory usage percentage [Current Storage Inventory / Storage Inventory at 7am].
"Design Basis" Cooling load profile		"Design Basis" storage inventory percentage for current time period
The "Design Basis" rate of change cooling load factors (7am through 8pm)		Anticipated storage inventory percentage in 1 hour.
Anticipated cooling load for the next hour [Rate of Change Load Factor x Average Cooling Load for Last 2 Hours]		Current Inventory percentage surplus or deficit
Hours that mode D is expected to be engaged (normally 7am to 8pm)		Current Inventory Ton-hour surplus or deficit

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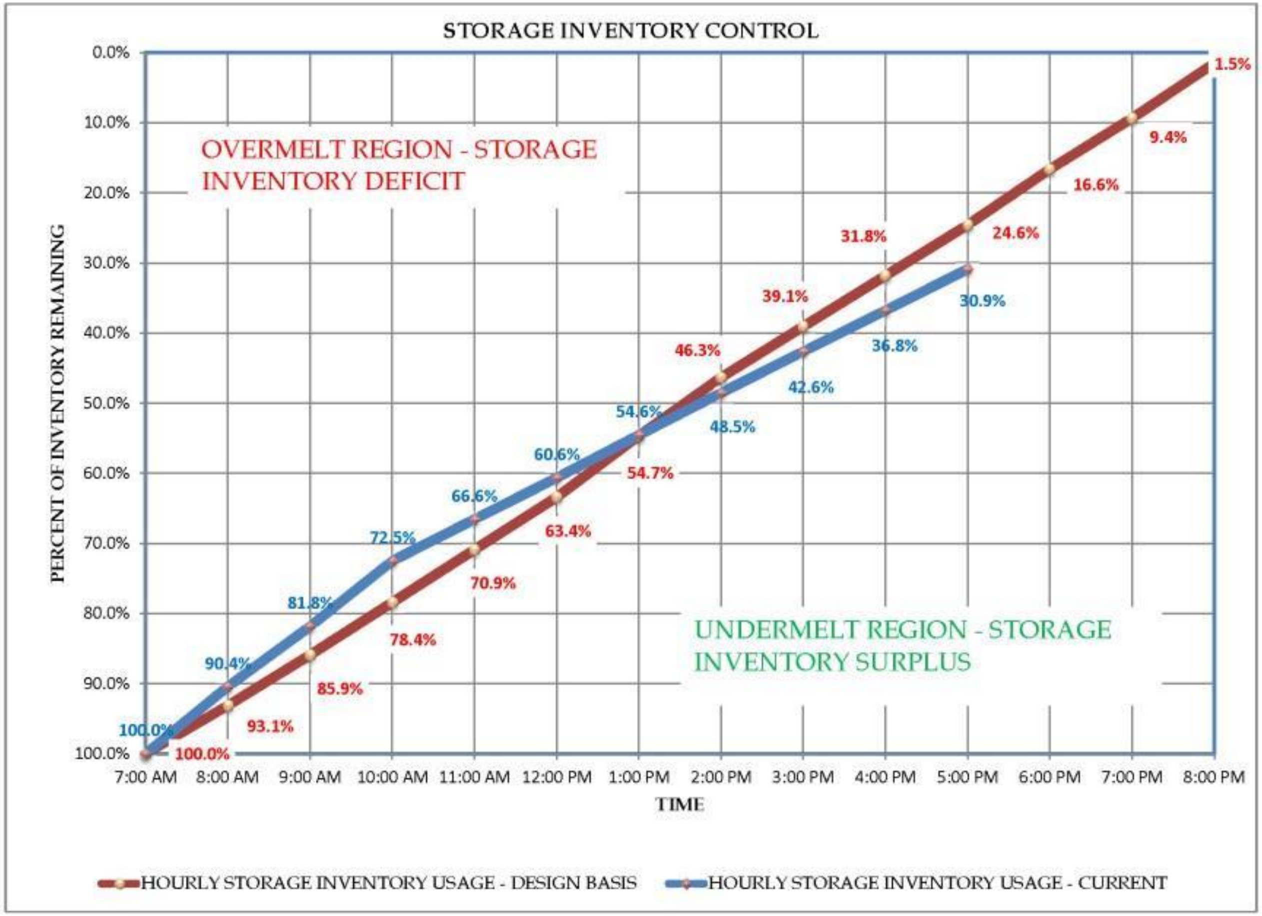
KAU CUP-2 Automation System

KING ABDULAZIZ UNIVERSITY - CUP II



Applications to UAE District Cooling

1. Use 34.0°F to 36.0°F chilled water supply temperature to increase return temperature from ETS and reduce distribution flow rates by over 30%. This can reduce pipe sizes for any planned piping or reduce pumping electrical input by about 40%. Provides flexibility when adding pipe runs to newly constructed buildings.

2. Use thermal energy storage, either ice-based or chilled water, along with adaptive use algorithms to reduce the electric power used during day time peak hours, and reduce the size of electric transformer that serve the plant.

3. Reduce construction costs by using a combination of constant speed and variable speed pumps to serve the distribution system.

4. Use the greater flexibility and more efficient chiller units that have become available since the KAU project to reduce the construction cost of ice-based thermal storage and improve the efficiency of both types of thermal storage.

Applications to UAE District Cooling

AHRI CERTIFIED™ www.ahridirectory.org

Application: AHRI 400 Version 15.1

Customer	**: Mr. Tom Brady**			
Project	**: Dubai**			
Item	**: HX-1**		**Date**	**: 9/13/2016**

Model:	**AQ14L-FG**			
		Hot Side		***Cold Side***
Fluid		Water		Water
Volume flow rate	GPM	2686.0		2681.2
Inlet temperature	°F	58.0		40.0
Outlet temperature	°F	42.0		56.0
Pressure drop	psi	9.88		9.92
Heat exchanged	kBtu/h		21600	
Mean temperature difference	°F		2.0	
Surface area	ft²		11741	
Density	lb/ft³	62.4		62.4
Specific heat	Btu/lb,°F	1.00		1.00
Thermal conductivity	Btu/ft,h,°F	0.339		0.338
Viscosity	cP	1.16		1.20
Plate material / Thickness			ALLOY 304 / 0.40 mm	
Sealing material		NBRP		NBRP
Connection material		Stainless steel		Stainless steel
Connection locations		S1 -> S2		S4 <- S3
Connection diameter	in	14		14
Pressure vessel code			ASME	
Design Temperature	°F	150.0		150.0
Design pressure	psi	150.0		150.0
Liquid volume	ft³	47.987		47.987
Overall length x width x height	in		158 x 45 x 126	
Net weight, empty / operating	lb		18100 / 24000	

Performance is ARI 400-2001 Certified.

1. Heat Exchangers and cooling coils can be selected with no change in performance within the building but allowing higher return temperature to the DC plant.

2. Since the sizing criteria for the heat exchanger (LMTD) is higher the price is lower.

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Applications to UAE District Cooling

AHRI CERTIFIED™ www.ahridirectory.org

Application: AHRI 400 Version 15.1

Customer : Mr. Tom Brady
Project : Dubai
Item : HX-2 **Date : 9/13/2016**

Model:	**AQ14L-FG**	***Hot Side***		***Cold Side***
Fluid		Water		Water
Volume flow rate	GPM	2158.0		1864.1
Inlet temperature	°F	60.0		36.0
Outlet temperature	°F	40.1		59.0
Pressure drop	psi	7.49		5.72
Heat exchanged	kBtu/h		21600	
Mean temperature difference	°F		2.2	
Surface area	ft²		10997	
Density	lb/ft³	62.4		62.4
Specific heat	Btu/lb,°F	1.00		1.00
Thermal conductivity	Btu/ft,h,°F	0.341		0.340
Viscosity	cP	1.13		1.14
Plate material / Thickness			ALLOY 304 / 0.40 mm	
Sealing material		NBRP		NBRP
Connection material		Stainless steel		Stainless steel
Connection locations		S1 -> S2		S4 <- S3
Connection diameter	in	14		14
Pressure vessel code			ASME	
Design Temperature	°F	150.0		150.0
Design pressure	psi	150.0		150.0
Liquid volume	ft³	44.986		44.986
Overall length x width x height	in		158 x 45 x 126	
Net weight, empty / operating	lb		17600 / 23100	

Performance is ARI 400-2001 Certified.

Item	Qty	Description	Price
HX-1	1	AQ14L-FG, with (507) ALLOY 304 plates with NBRP CLIP-ON gaskets.	$128,000.00
HX-2	1	AQ14L-FG, with (475) ALLOY 304 plates with NBRP CLIP-ON gaskets.	$122,600.00

LMTD for higher temperature return heat exchanger is 2.2. The heat transfer surface and the price for the heat exchanger are both lower. Note that the average water temperature at a cooling coil in the building is the same 50.0°F.

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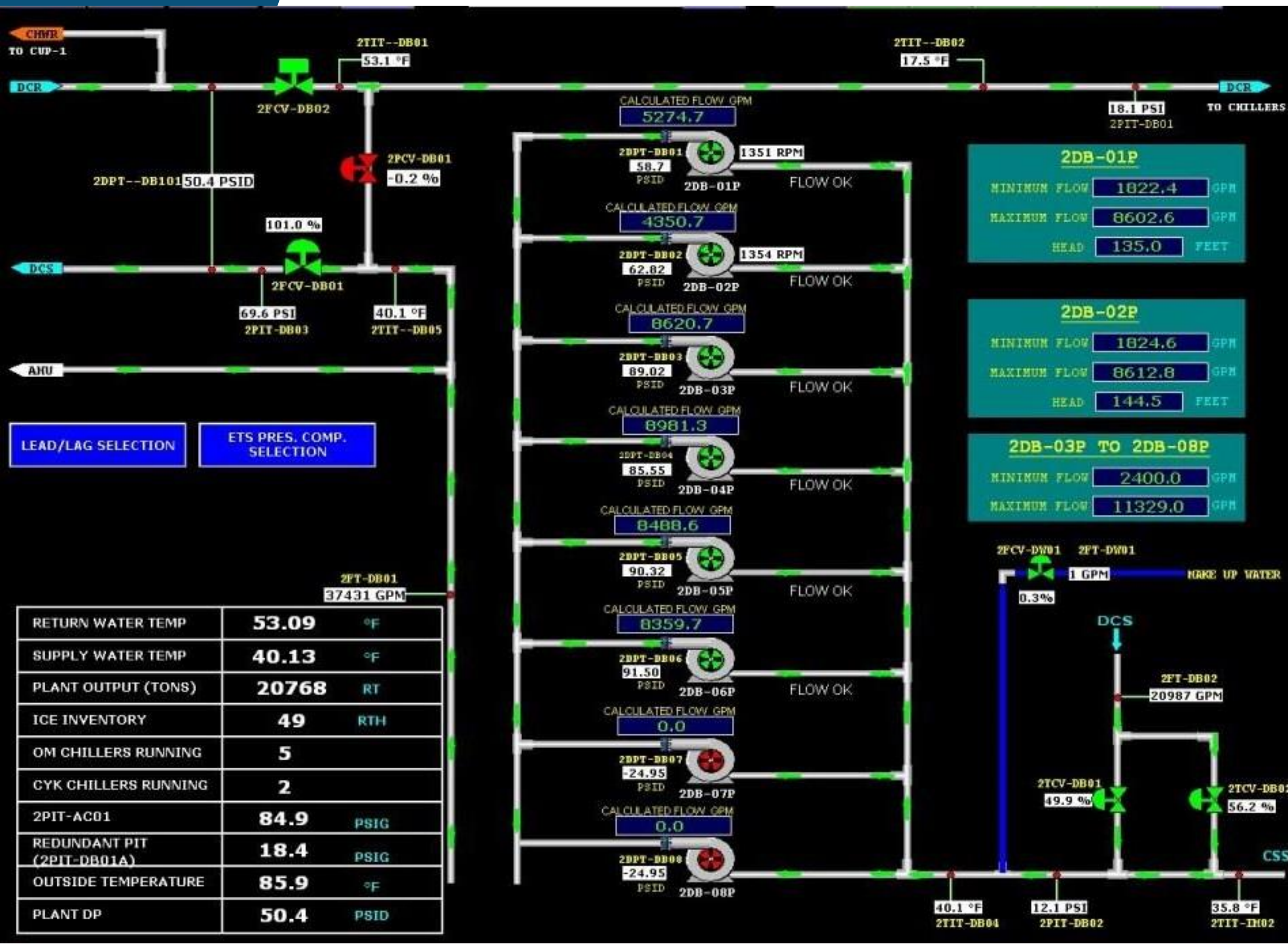
Applications to UAE District Cooling



Combining variable speed and constant speed pumps has been done successfully for decades. Care must be taken to include the proper operating and limit safeguards. With the cost of MV VFDs the extra time spent in design is well worth the effort.

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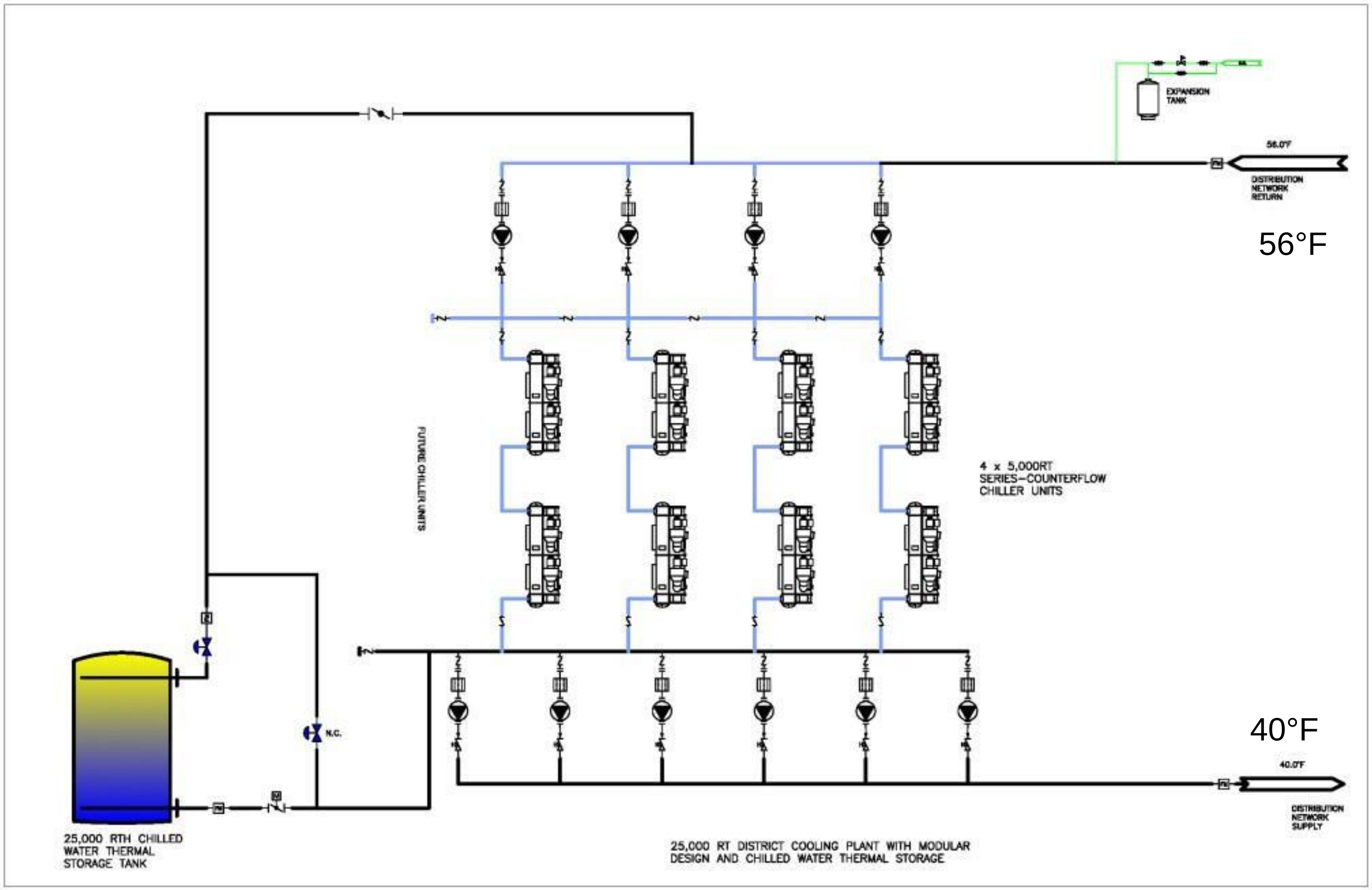
UAE DC Design with CHW Thermal Storage



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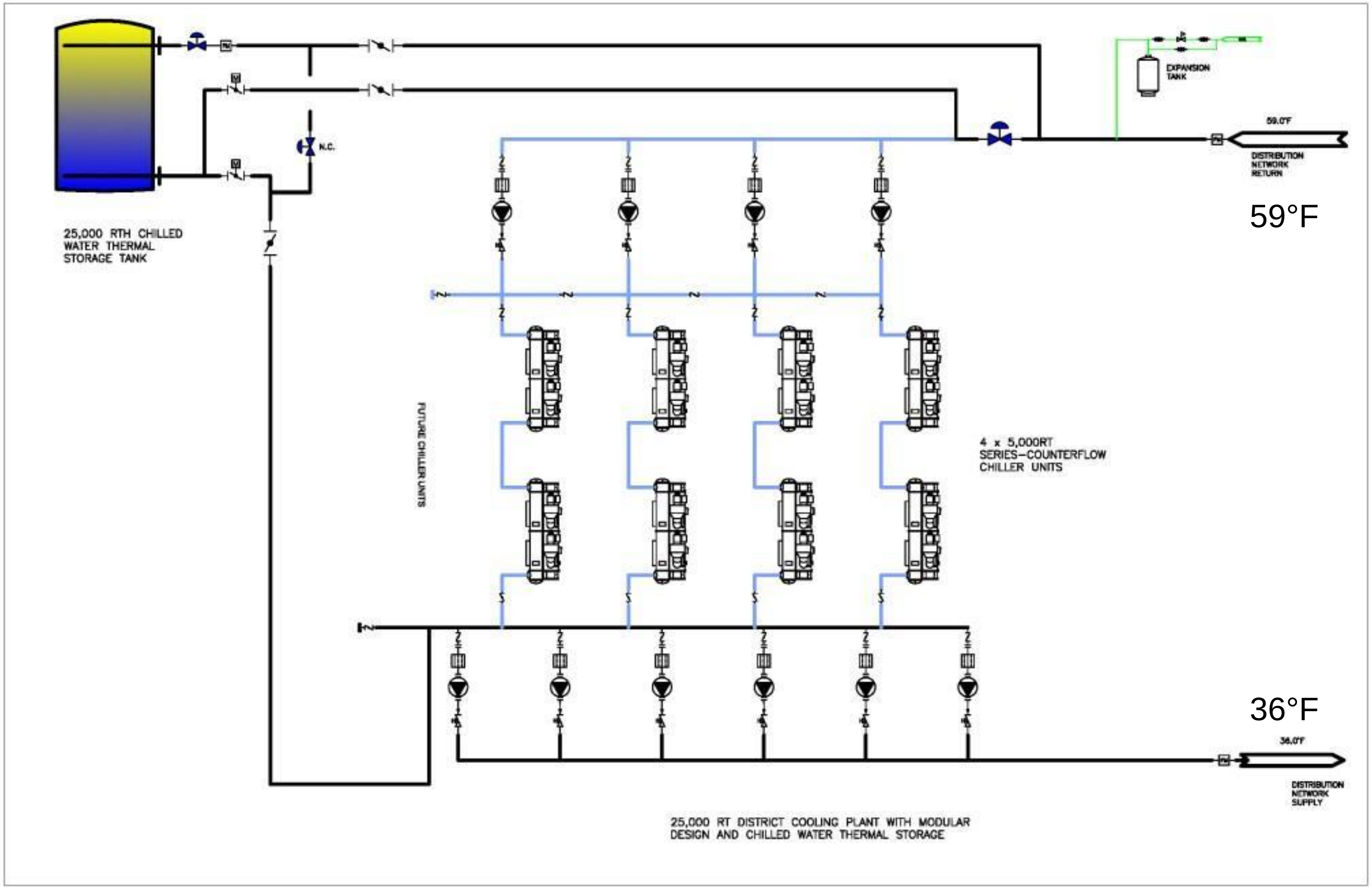
Reduced Temperature Design with CHW Thermal Storage



Conclusion

THANK YOU