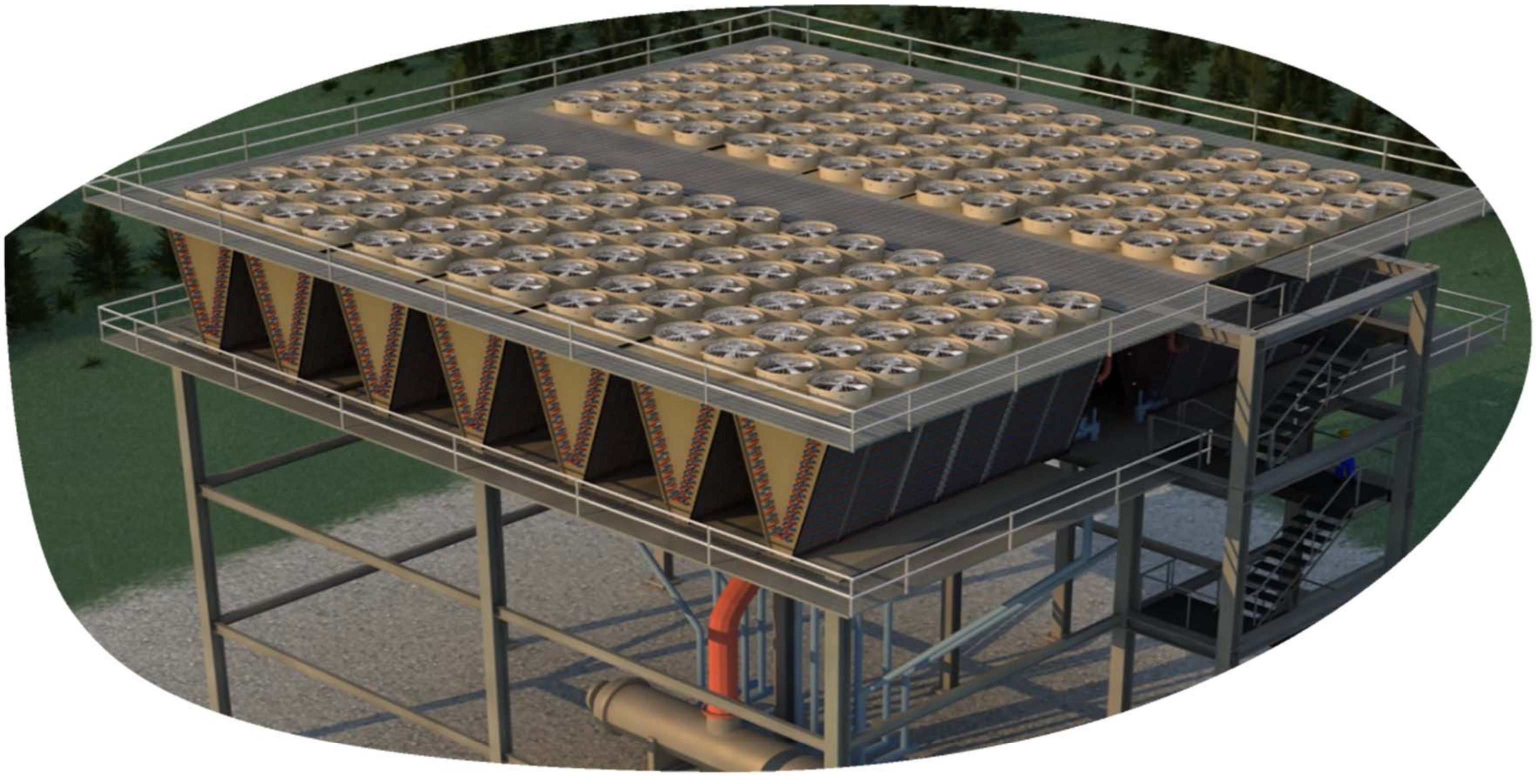
Innovative Water Saving District Cooling Plant Designs Using Thermosyphon Cooler Hybrid System Technology



District Cooling 2014 Conference
Dubai, UAE

December 15, 2014

Johnson Controls

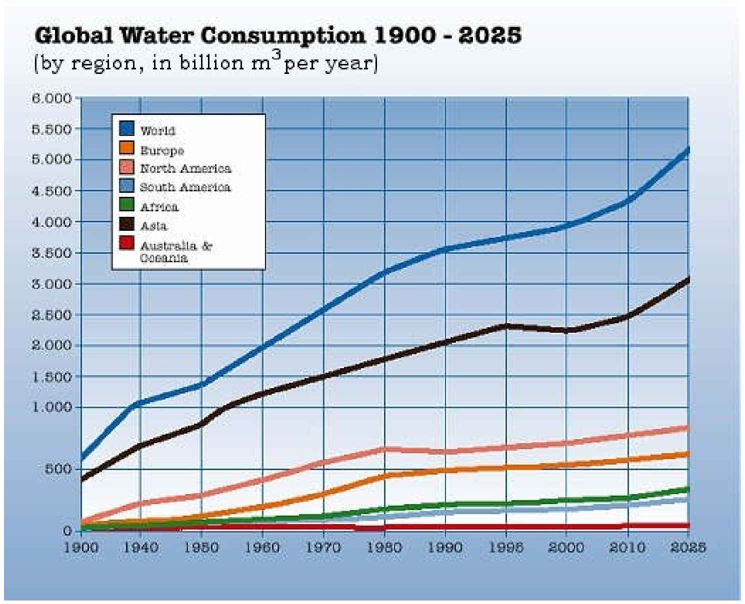
Freshwater Stress - The Global Perspective

Forces Driving Fresh Water Consumption:

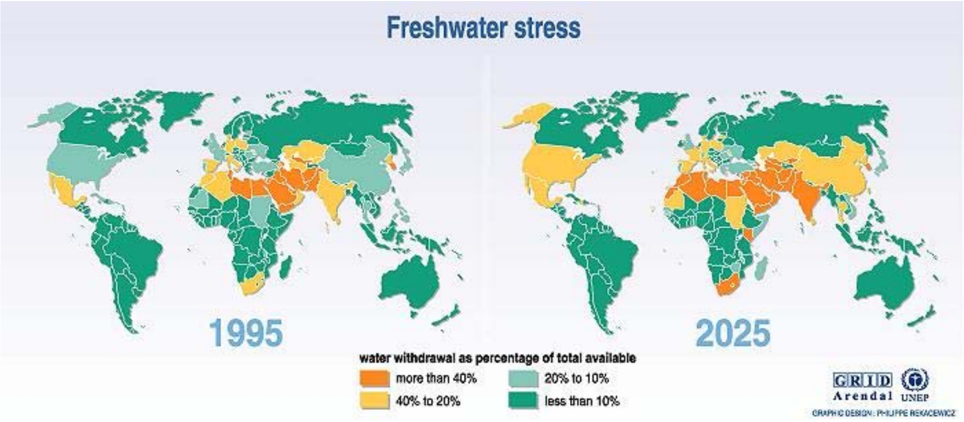
- **Population growth increases total demand**

- **Economic growth increases per capita demand**

Consumption increases …



driving Freshwater Stress worldwide



Source: Global environment outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

Evaporative Heat Rejection - The Primary Driver of Water Consumption in Chiller Plants

Advantages

- Produces much cooler process temperatures than dry cooling which will:
  - improve chiller efficiency
  - improve chiller capacity
- Lower in first cost than dry cooling
- Requires less parasitic energy than dry cooling
- Requires less plan area than dry cooling

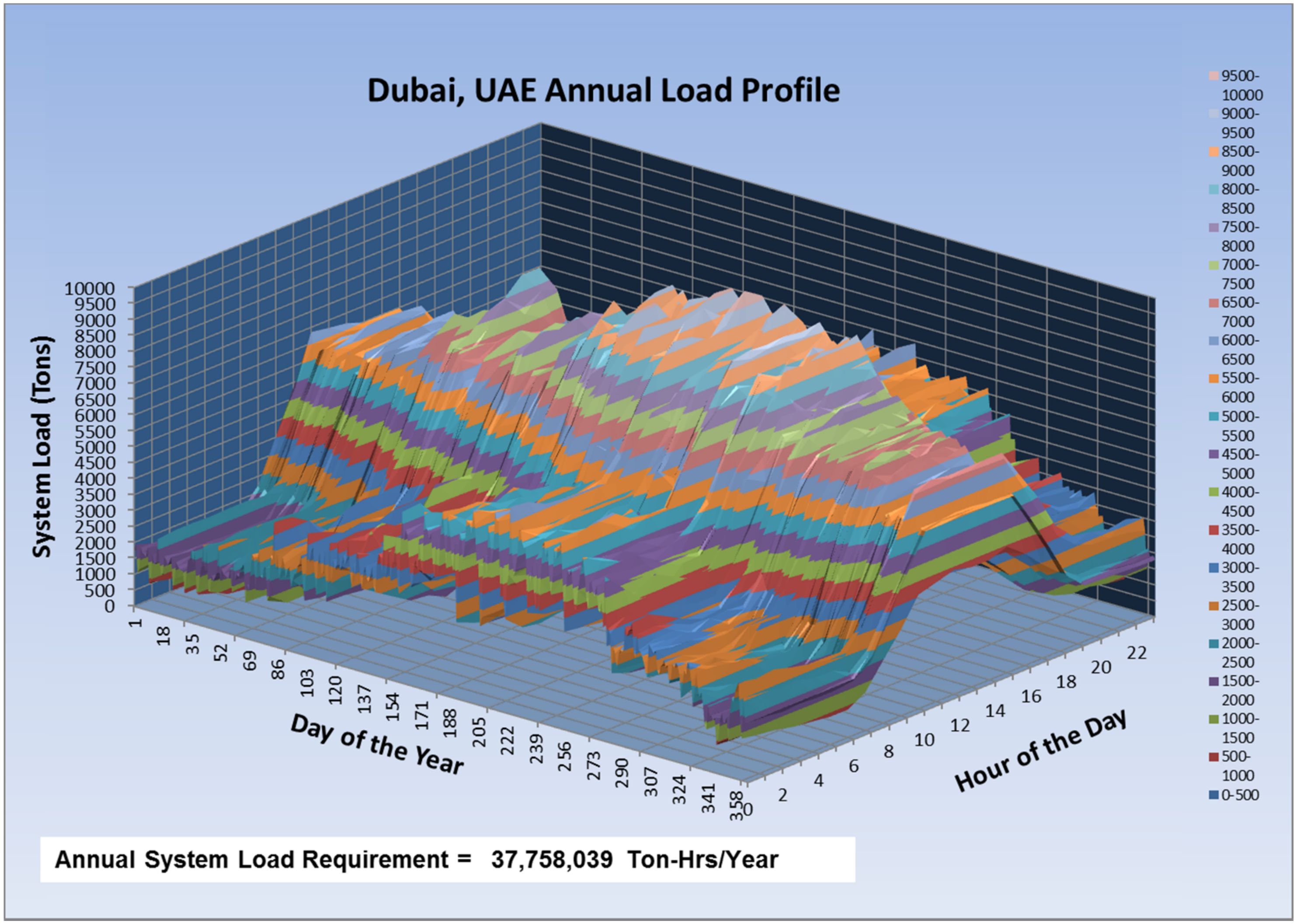
Disadvantages

- Consumes massive amounts of water and produces waste water
- Requires chemical water treatment to combat issues related to corrosion, scale, and biological growth
- Creates potential for plume in cooler weather
- Potential for icing issues in freezing weather

The Challenge:

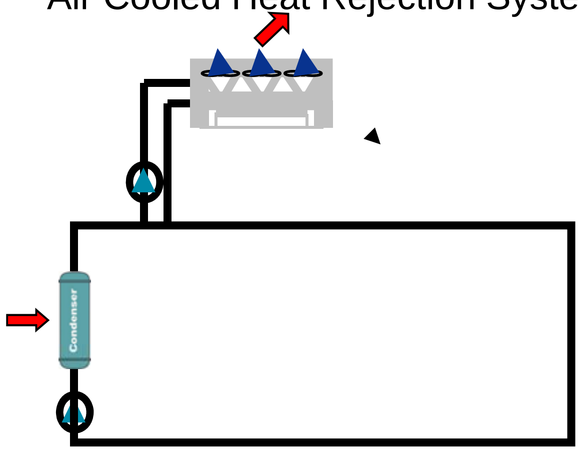
How can the efficiency and capacity advantages of Evaporative Heat Rejection be delivered with far less water consumption?

10,000 Peak Load District Cooling System Located in Dubai

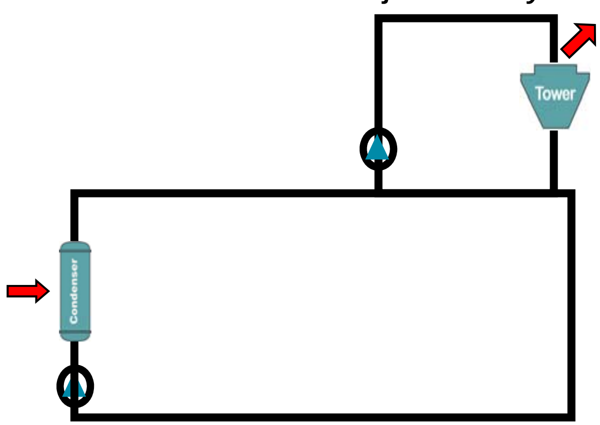


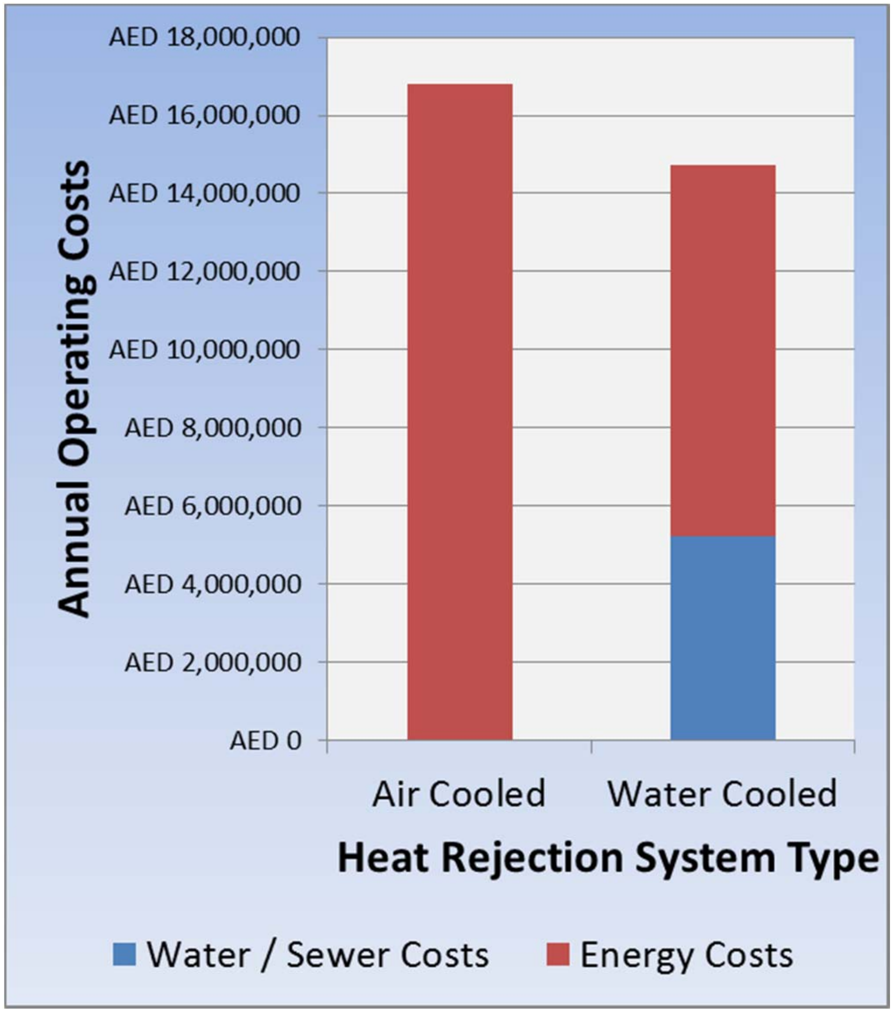
Dry and Water Cooled Heat Rejection System Options

Air Cooled Heat Rejection System



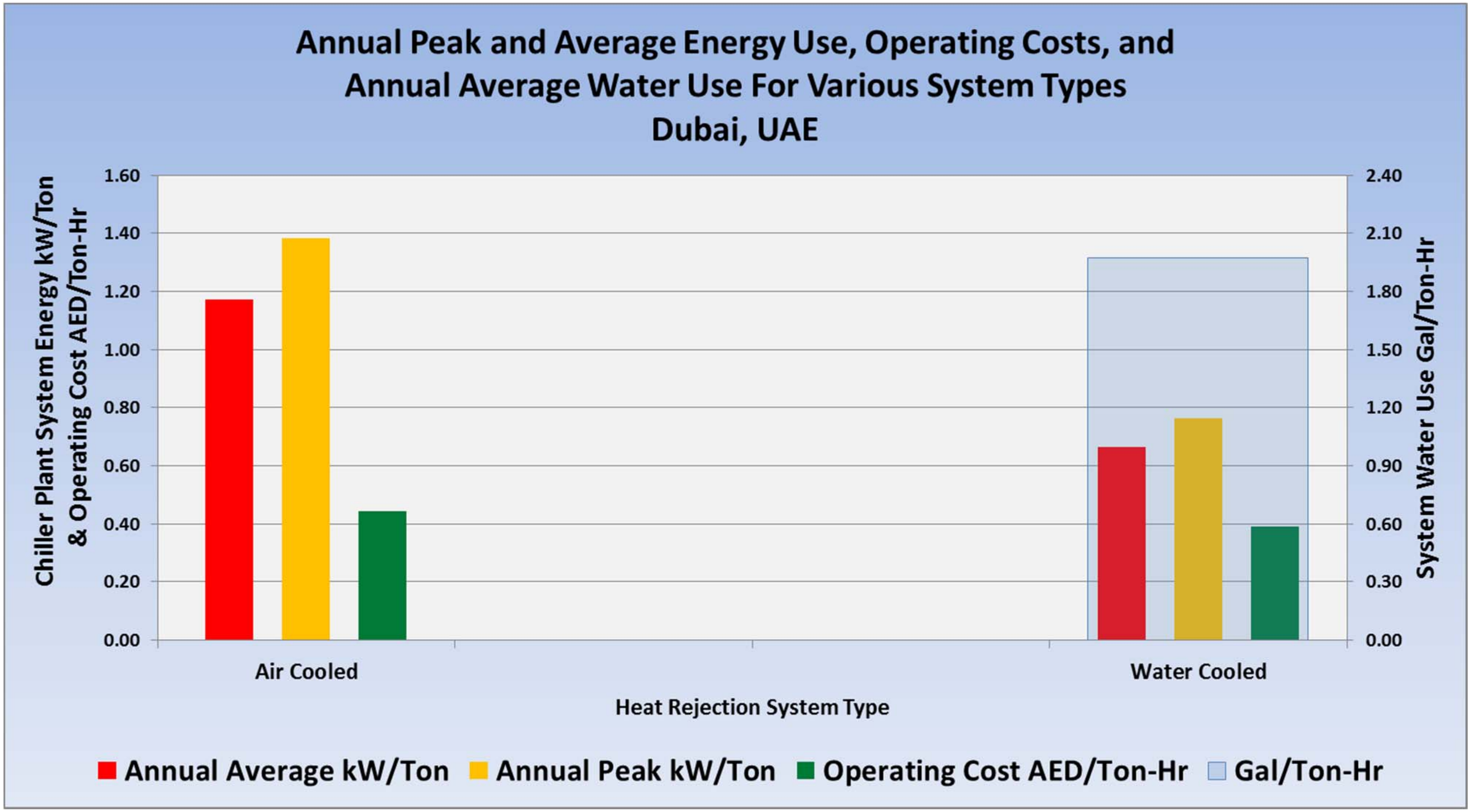
Water Cooled Heat Rejection System





Air Cooled Heat Rejection

A Water Smart but Energy Intensive Option



Assumptions
- Energy Evaluated at AED 0.38/kWh
- Water Evaluated at AED 70.79 / 1000 US Gal (Includes sewer & chemical charges applied to blowdown)

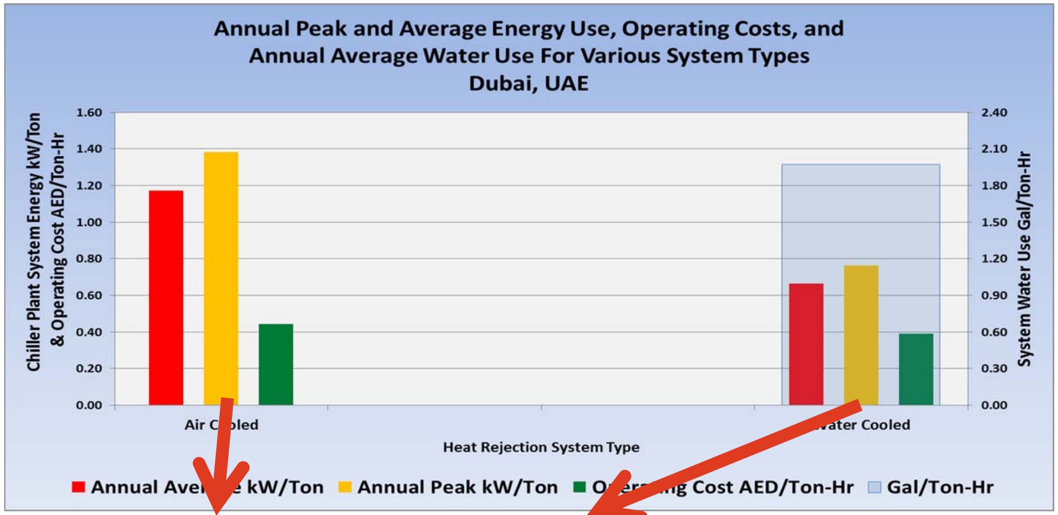
Air Cooled Vs. Water Cooled – A Closer Look

Air Cooled System

- Water Cooled Chiller plus Radiator
- Cooling Water Flow: 3 GPM/Ton
- Cooling Water Control: 13°C min.

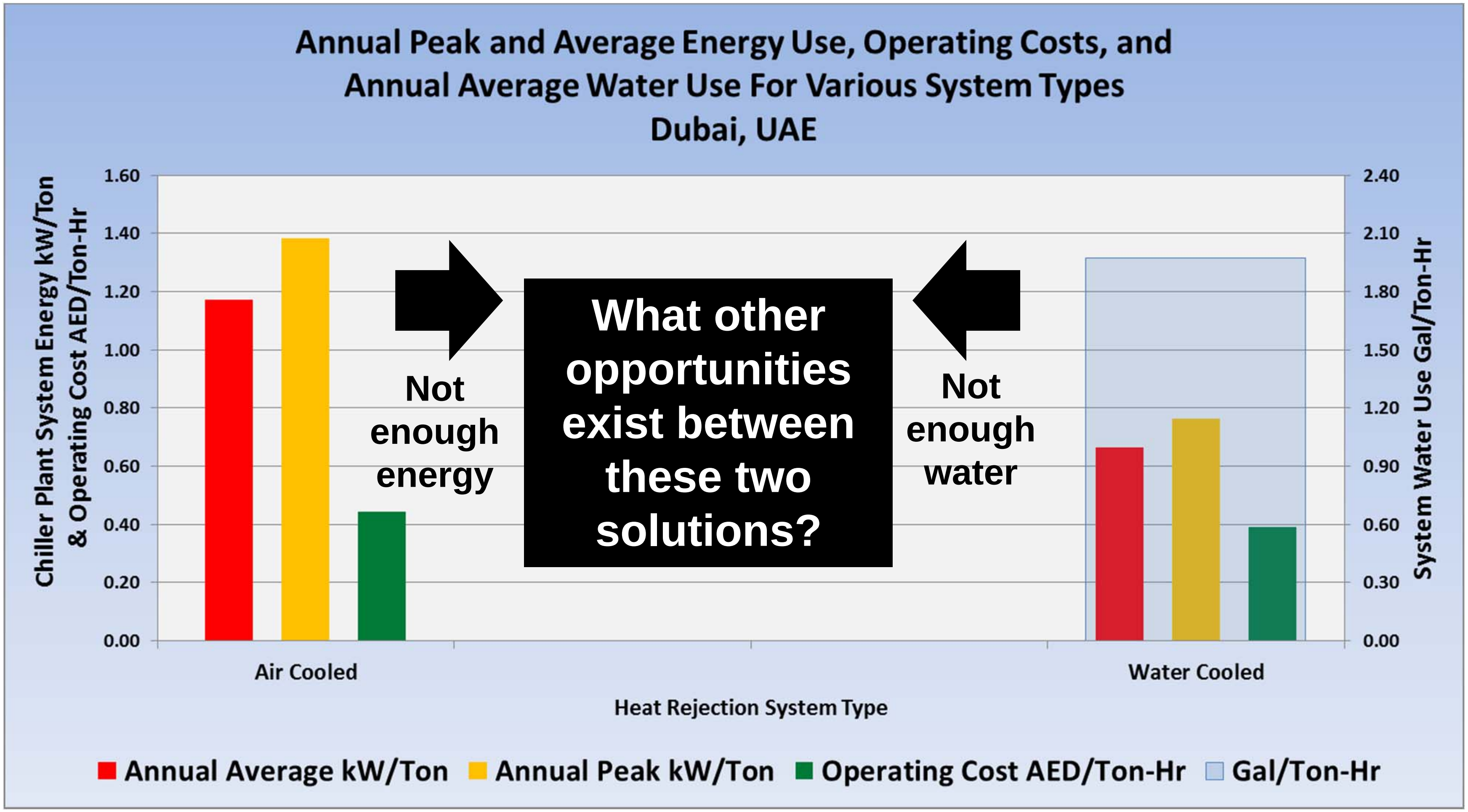
Water Cooled System

- Water Cooled Chiller plus Open Cooling Tower
- Cooling Water Flow: 3 GPM/Ton
- Cooling Water Control: 13°C min



System Metrics	Air Cooled System	Water Cooled System	Percent Difference
Average kW / Ton	1.171	.663	+76.6%
Peak kW / Design Ton	1.383	.763	+81.3%
Operating Cost AED / Ton-Hr	.445	.390	+14.0%
Water Use Gal / Ton-Hr	0	1.974	-100.0%

Air-Cooled System vs Water-Cooled System – Dubai, UAE



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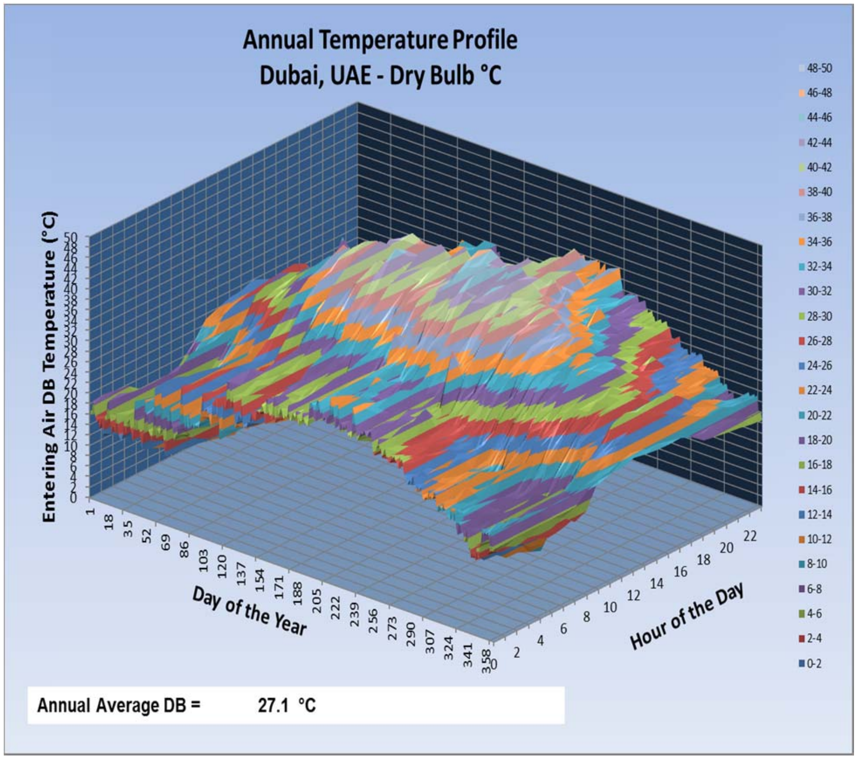
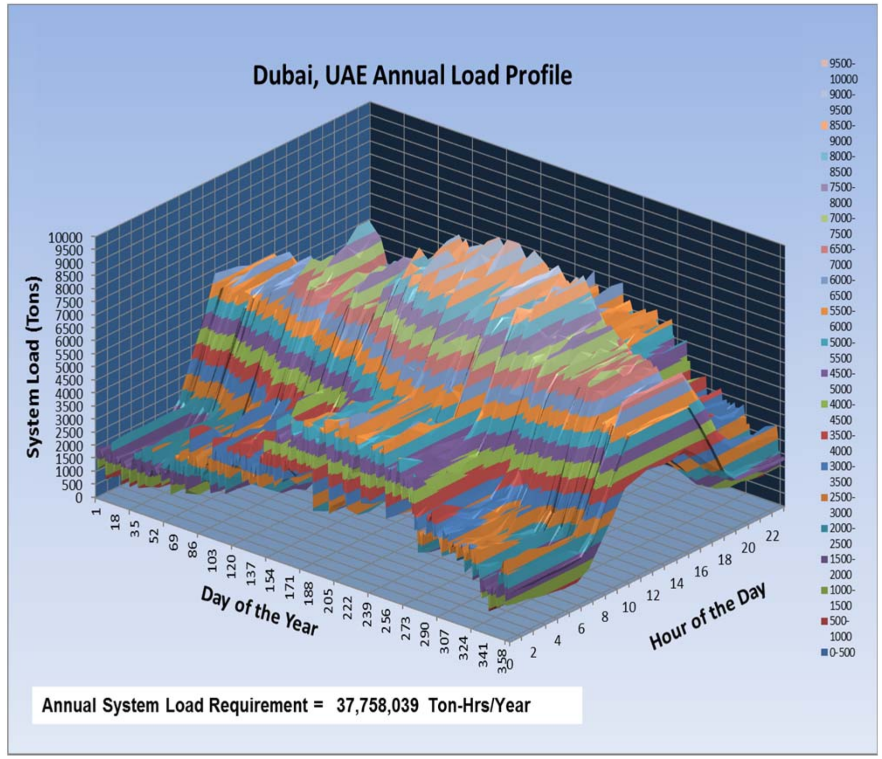
Weather and Load Variations Provide Opportunities

DB



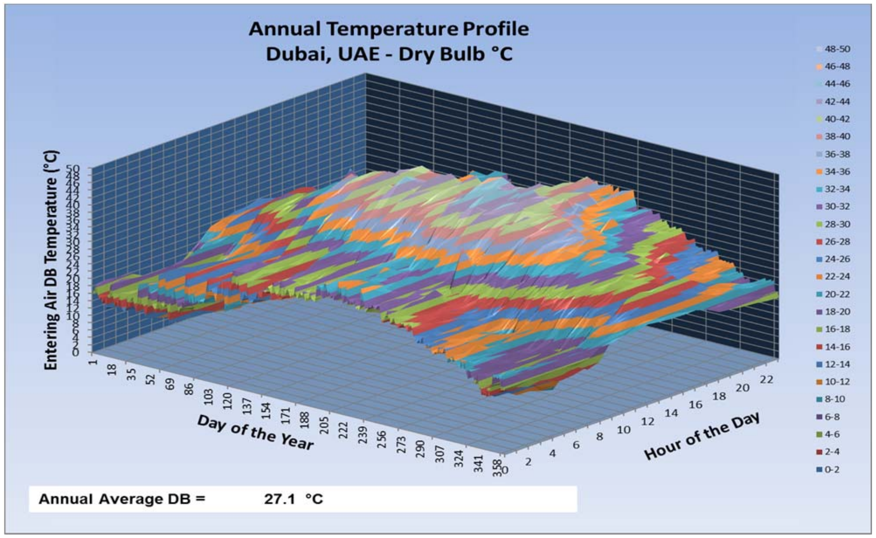
Thermal Load



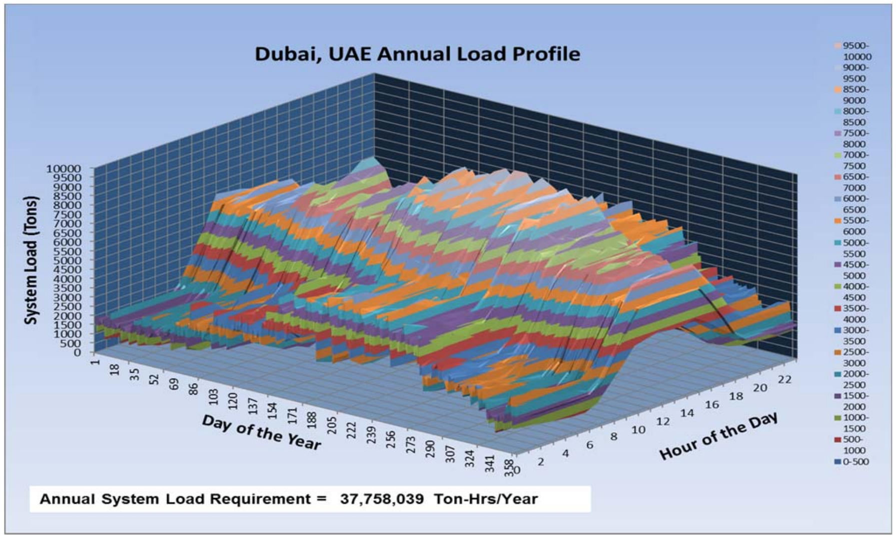
Hybrid Wet / Dry Solutions

- Basic Principles:
  - Operates wet during peak periods to save energy (high temperatures and loads)
  - Operates dry during off peak periods to save water (lower temperatures and loads)
  - May be capable of operating both wet and dry during moderate periods

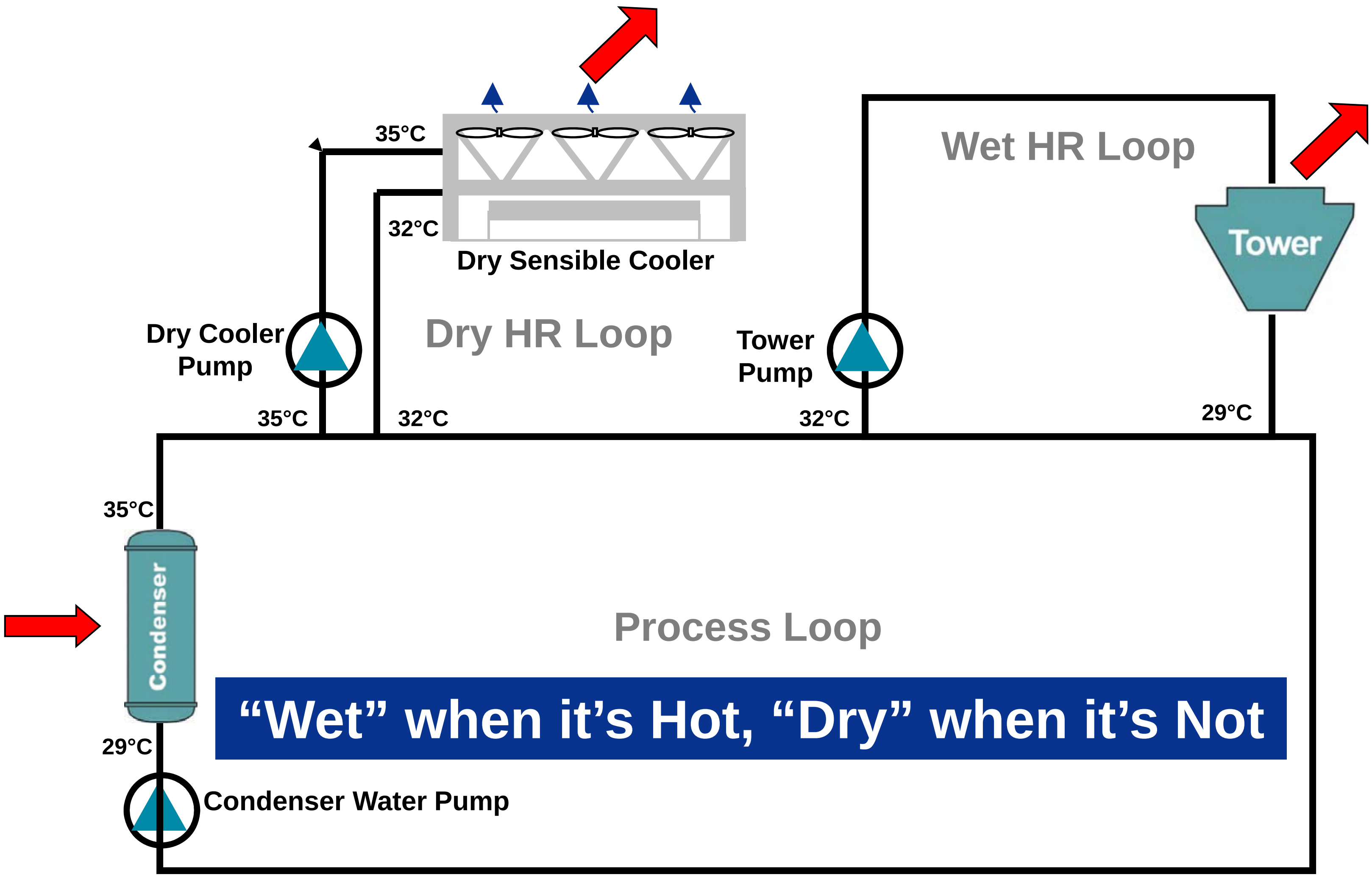
DB



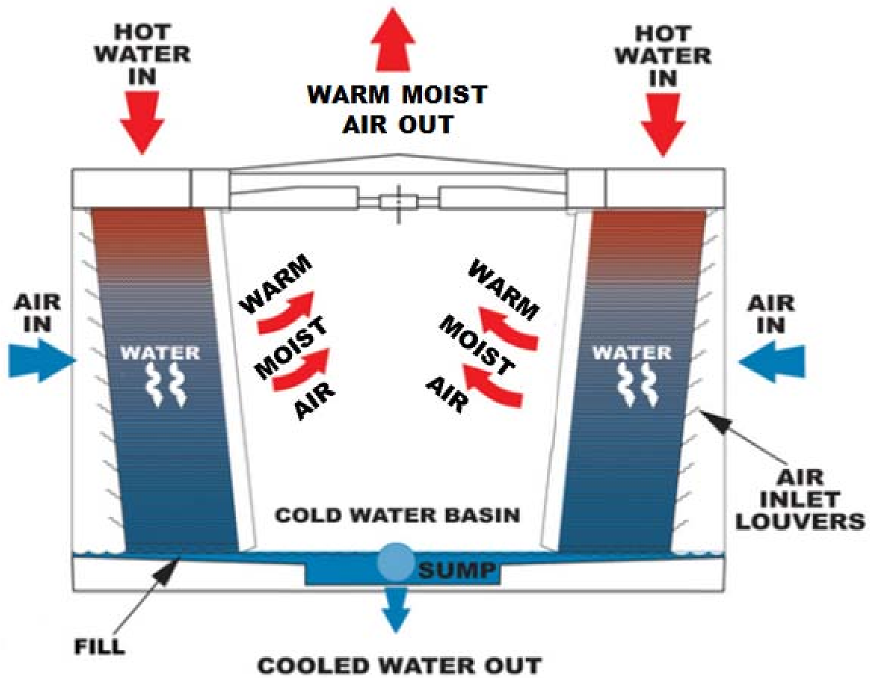
Thermal Load



Series Flow Dry / Wet Hybrid Heat Rejection System

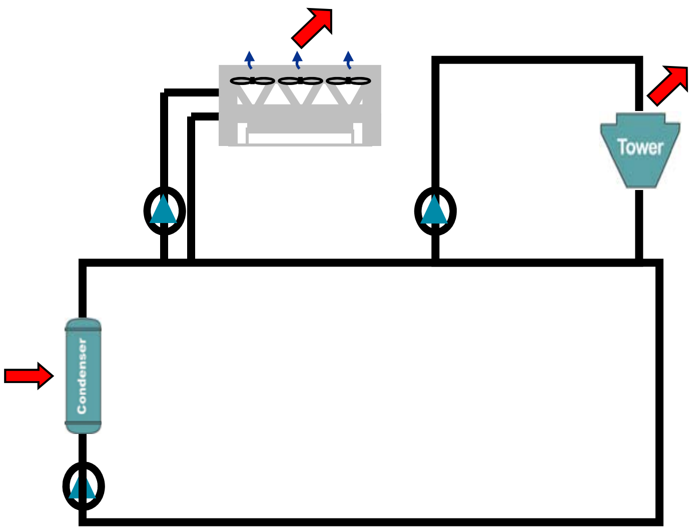


The Open Cooling Tower is Very Efficient and It's Desirable to Have it as Part of a Hybrid System



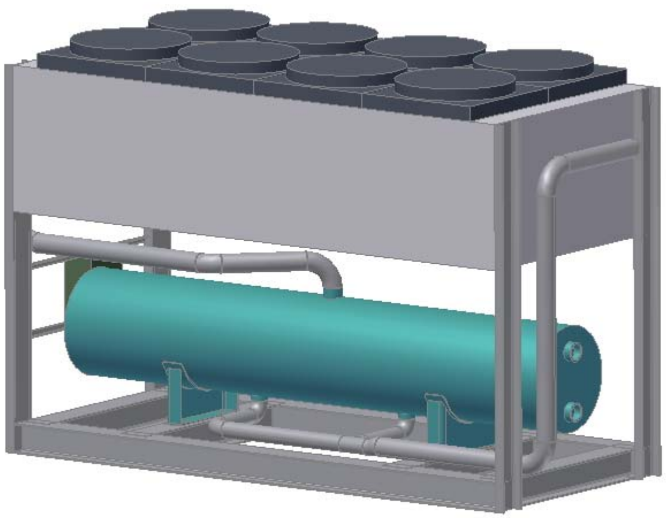
- Highly efficient – because it has the ability to saturate the exit air stream with moisture it can reject the same amount of heat as a dry system with about 80% less air… this leads to:
  - Significantly lower cost
  - Significantly smaller footprint
  - Significantly lower fan energy
- It can also operate against the lower WB temperature heat sink instead of the higher DB heat sink… especially important on those design days when the WB depression is typically the greatest

Dry Sensible Heat Exchanger Requirements



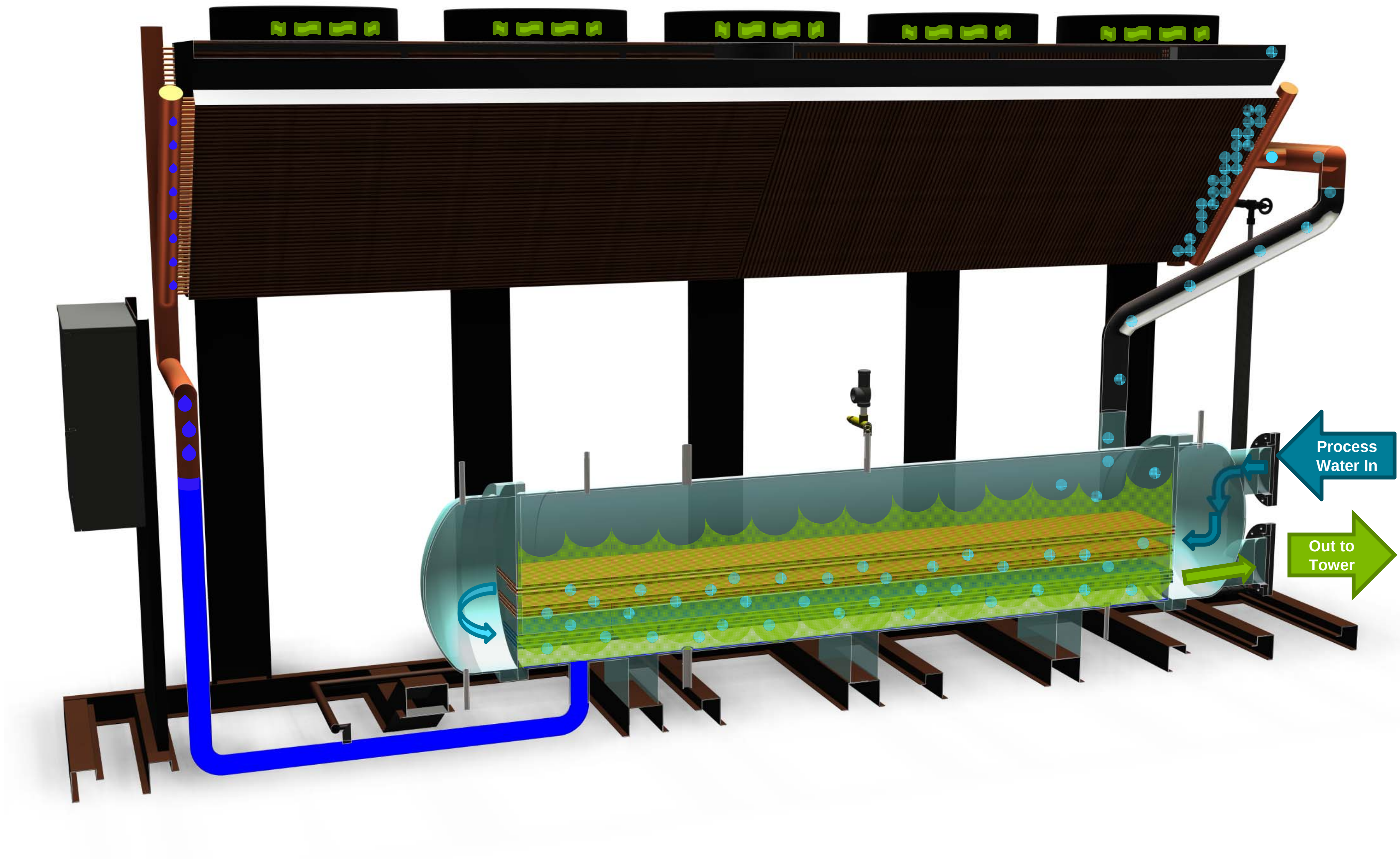
- Seems simple enough but there are several issues that need to be dealt with:
  - Open system – cleanability issues, material compatibility issues
  - Low pressure drop design
  - Control issues (how do you balance the fan energy between the two pieces of equipment and the condenser loop temperatures that impact the chiller energy to achieve the greatest system benefit?)
  - Freeze protection

Thermosyphon Cooler (TSC) - a Dry Sensible Cooling Device Specifically Designed for Application in Open Cooling Water Systems



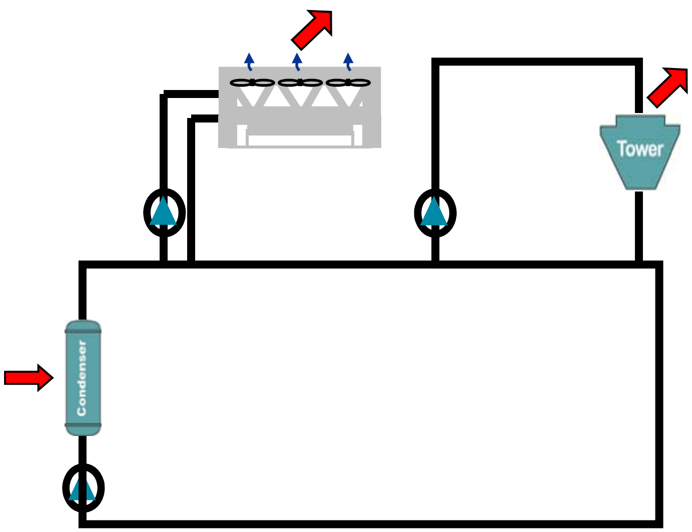
- Cleanable heat exchanger
  - Enables efficient contact with open cooling water
- Low waterside pressure drop
  - 1 – 4 psi minimizes pumping energy
- No intermediate fluid pump required
  - Uses natural circulation of refrigerant
- Control system designed for <u>cost optimized</u> balance between water and energy use
- No need for antifreeze
  - Freeze protection accomplished by controlling refrigerant flow

Thermosyphon Cooler – Conceptual Design



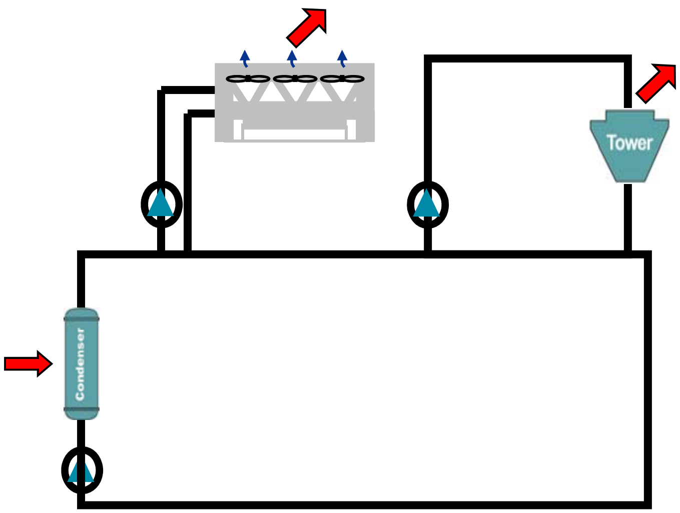
System Control Considerations for Operating Cost Optimization

■ **WECER** = **W**ater to **E**nergy **C**ost **E**quivalence **R**atio



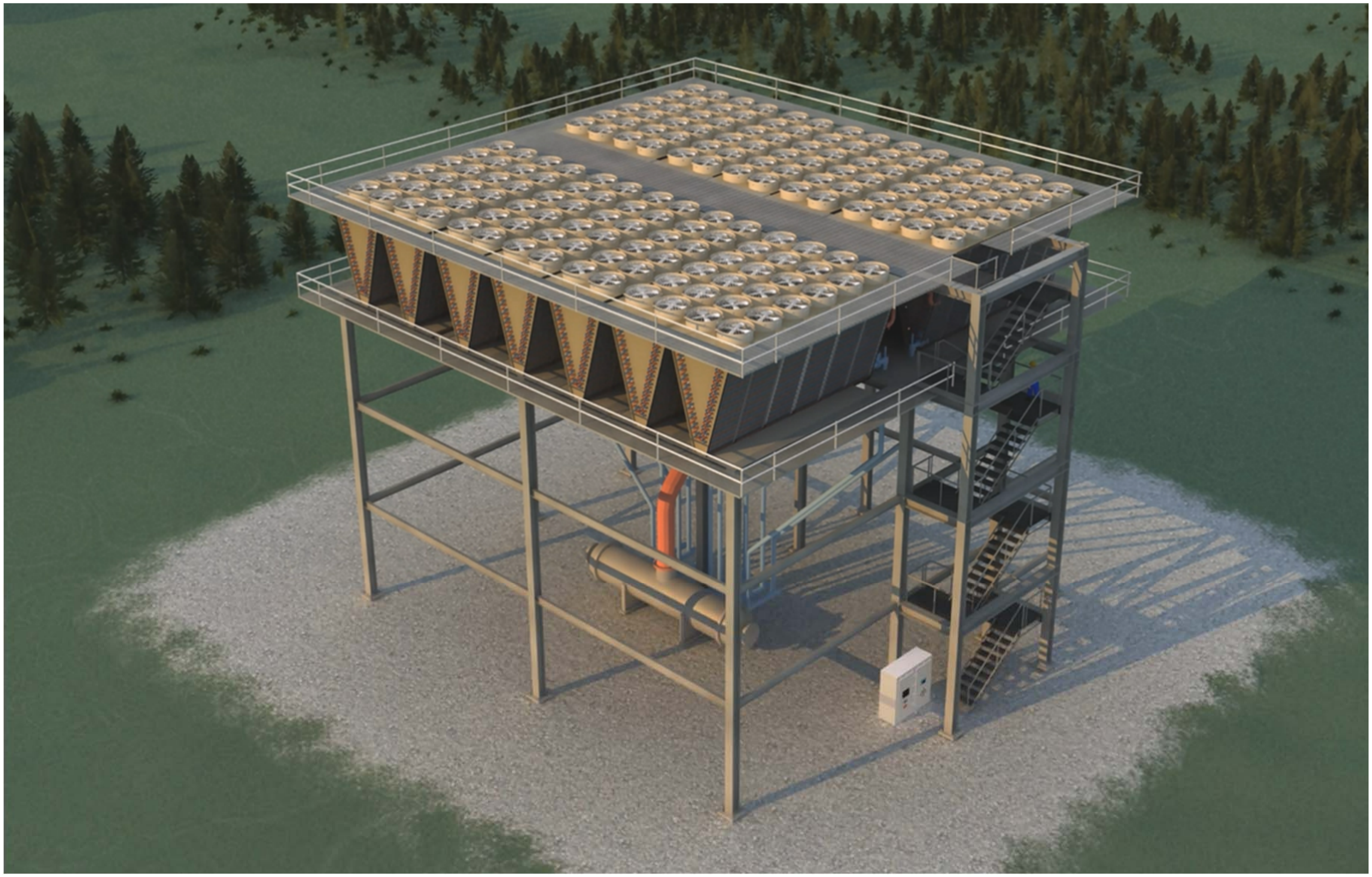
- **WECER = $\dfrac{\textbf{Additional Hybrid Heat Rejection System kWh}}{\textbf{1000's of Gallons of Water Saved}}$**
- **WECER = Cost of Water / Cost of Electricity**
- **WECER = (\$/1000 gal Water) / (\$/kWh)**
- **WECER = kWh / 1000 gal**

System Control Considerations for Maximum Water Savings



- Run the dry cooler fans at their maximum speed
- Elevate the condenser water loop temperatures to the maximum temperatures acceptable to the chiller

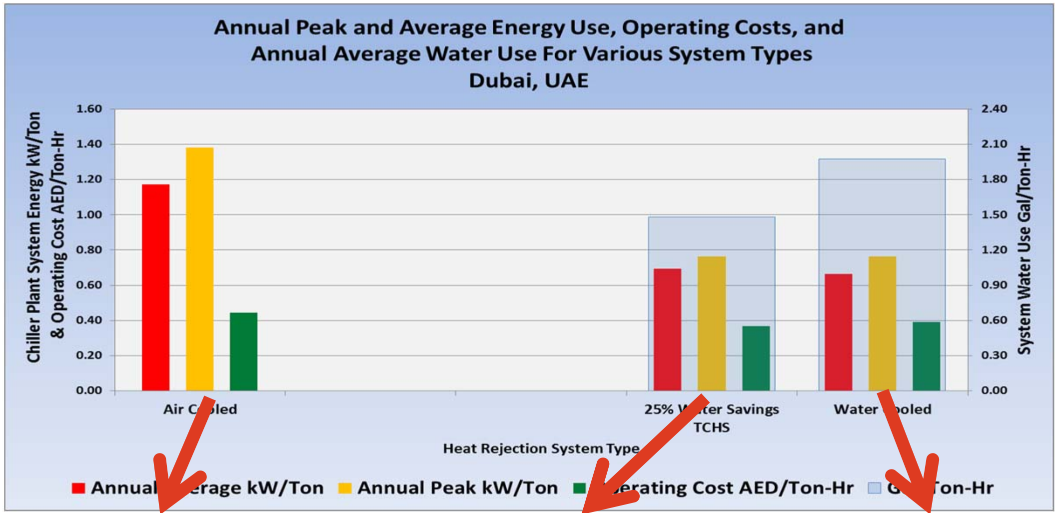
Larger Capacity 14 Condenser Unit TSC Module



25% Water Savings TSC Hybrid System Example

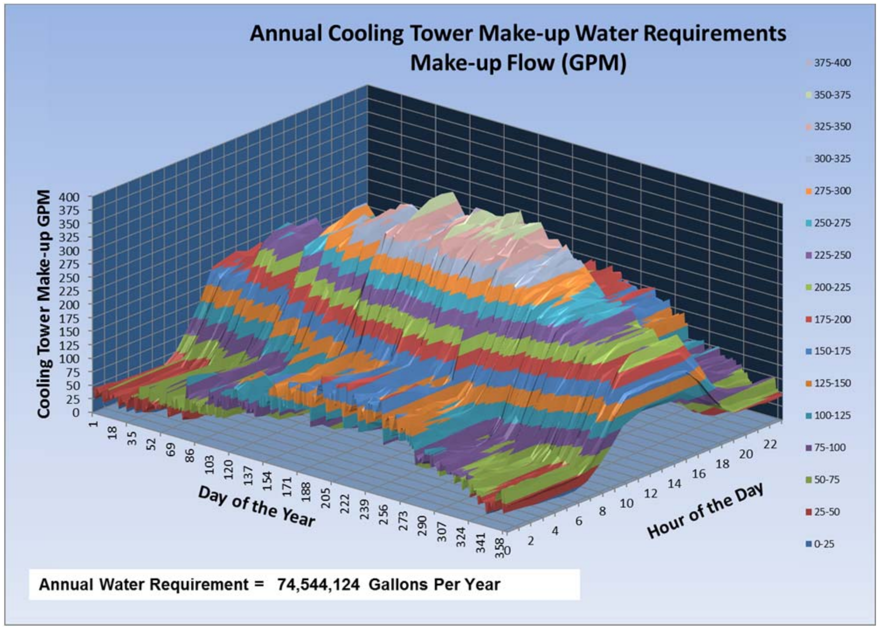
TSC Hybrid System

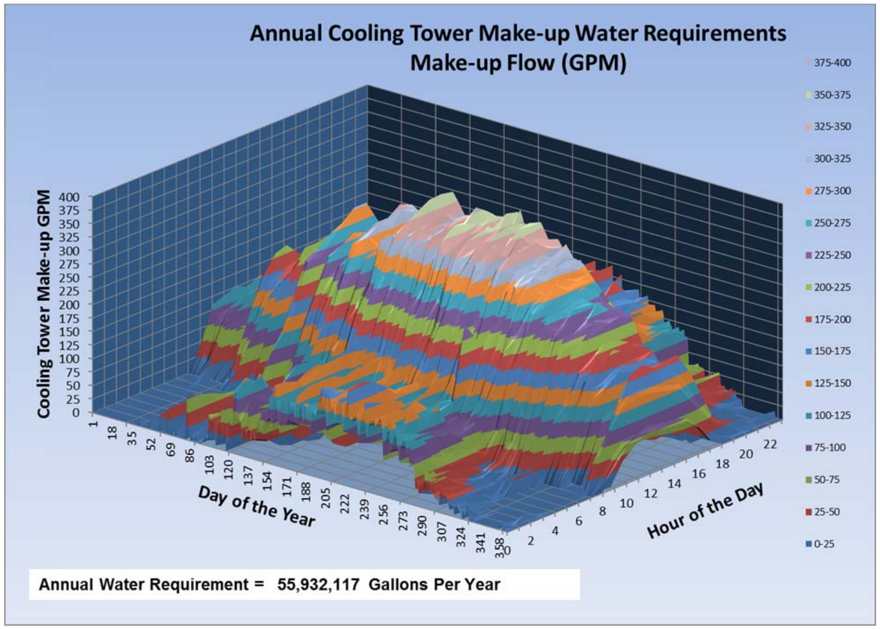
- Water Cooled Chiller plus TSC Modules plus Open Cooling Tower
- Cooling Water Control: WECER
- Cooling Water Min. Temp.: 29.0°C



System Metrics	Air Cooled System	Compared to Water Cooled	25% TSC Hybrid System	Compared to Water Cooled	Water Cooled System
Average kW / Ton	1.171	+76.6%	.692	+4.4%	.663
Peak kW / Design Ton	1.383	+81.3%	.763	+0.0%	.763
Operating Cost AED / Ton-Hr	.445	+14.0%	.368	-5.7%	.390
Water Use Gal / Ton-Hr	0	-100%	1.481	-25.0%	1.974

Cooling Tower Annual Make-up Water Requirements





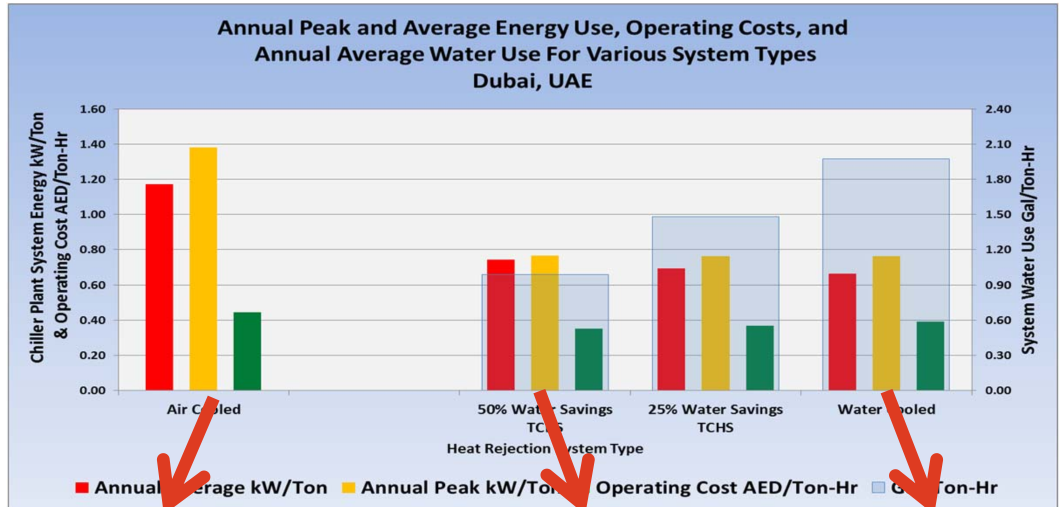
Cooling Tower Only System
Annual Water Use = 282,204 m^3

TCHS System 25% Savings
Annual Water Use = 211,744 m^3
Saving 70,460 m^3 / Year

50% Water Savings TSC Hybrid System Example

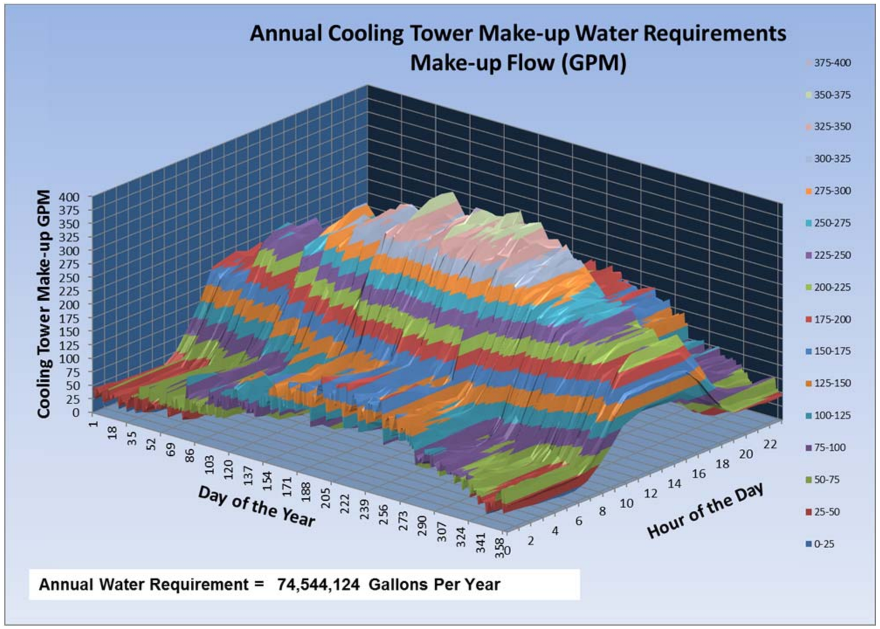
TSC Hybrid System

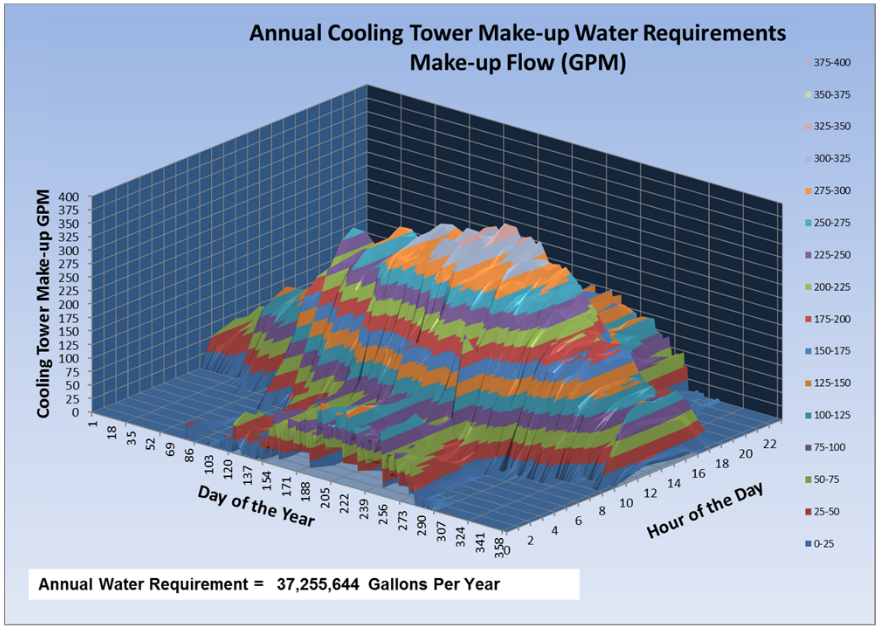
- Water Cooled Chiller plus TSC Modules plus Open Cooling Tower
- Cooling Water Control: WECER
- Cooling Water Min. Temp.: 35.8°C



System Metrics	Air Cooled System	Compared to Water Cooled	50% TSC Hybrid System	Compared to Water Cooled	Water Cooled System
Average kW / Ton	1.171	+76.6%	.742	+11.9%	.663
Peak kW / Design Ton	1.383	+81.3%	.767	+0.5%	.763
Operating Cost AED / Ton-Hr	.445	+14.0%	.352	-9.9%	.390
Water Use Gal / Ton-Hr	0	-100%	.987	-50.0%	1.974

Cooling Tower Annual Make-up Water Requirements





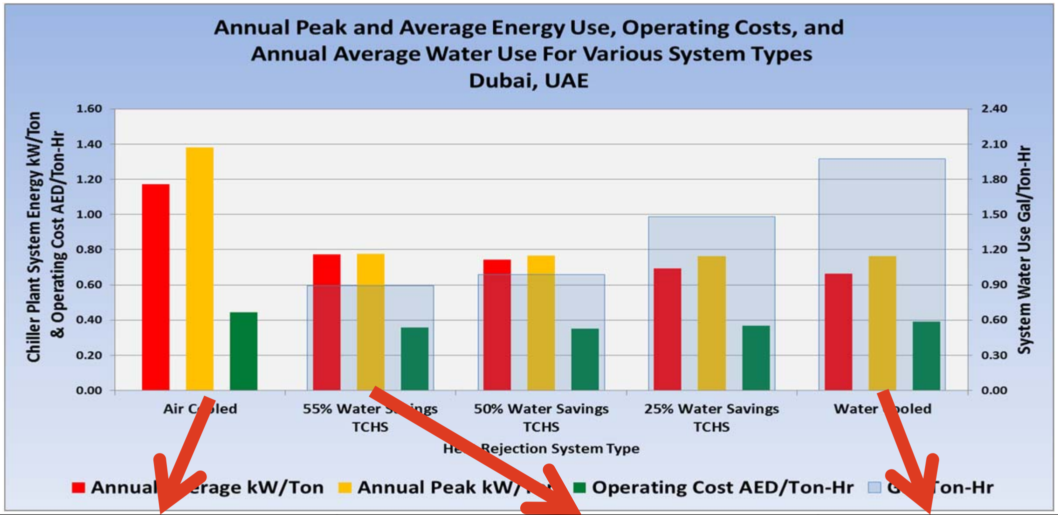
Cooling Tower Only System
Annual Water Use = 282,204 m^3

TCHS System 50% Savings
Annual Water Use = 141,040 m^3
Saving 141,164 m^3 / Year

55% Maximum Water Savings TSC Hybrid System Example

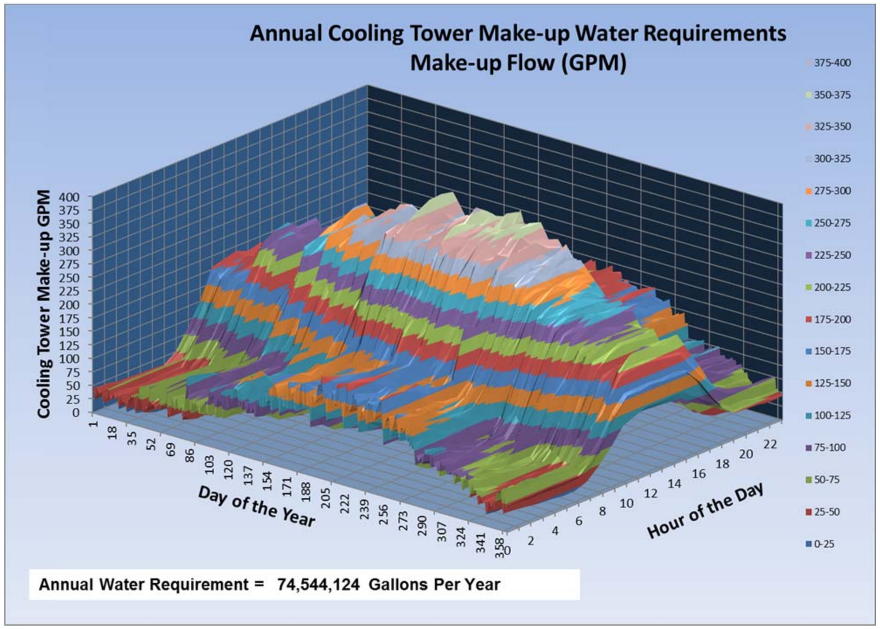
TSC Hybrid System

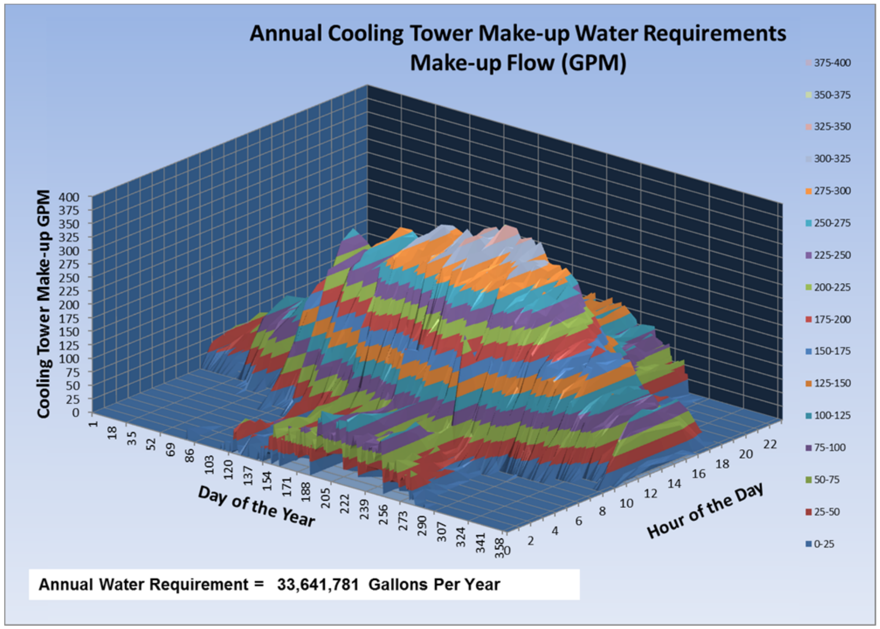
- Water Cooled Chiller plus TSC Modules plus Open Cooling Tower
- Cooling Water Control: Full Fan Speed
- Cooling Water Min. Temp.: 36.0°C



System Metrics	Air Cooled System	Compared to Water Cooled	55% TSC Hybrid System	Compared to Water Cooled	Water Cooled System
Average kW / Ton	1.171	+76.6%	.774	+16.7%	.663
Peak kW / Design Ton	1.383	+81.3%	.775	+1.6%	.763
Operating Cost AED / Ton-Hr	.445	+14.0%	.357	-8.5%	.390
Water Use Gal / Ton-Hr	0	-100%	0.891	-54.9%	1.974

Cooling Tower Annual Make-up Water Requirements

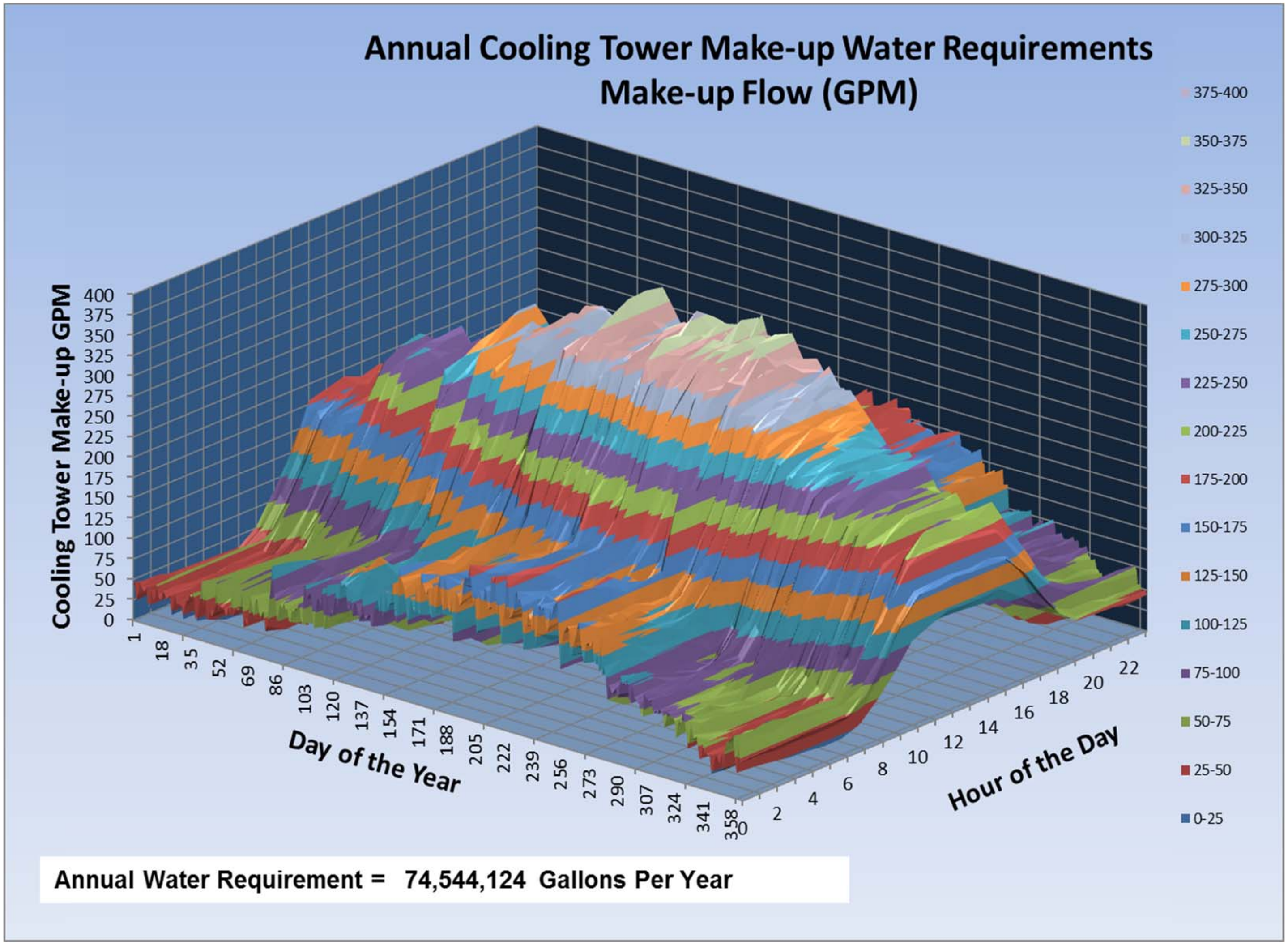


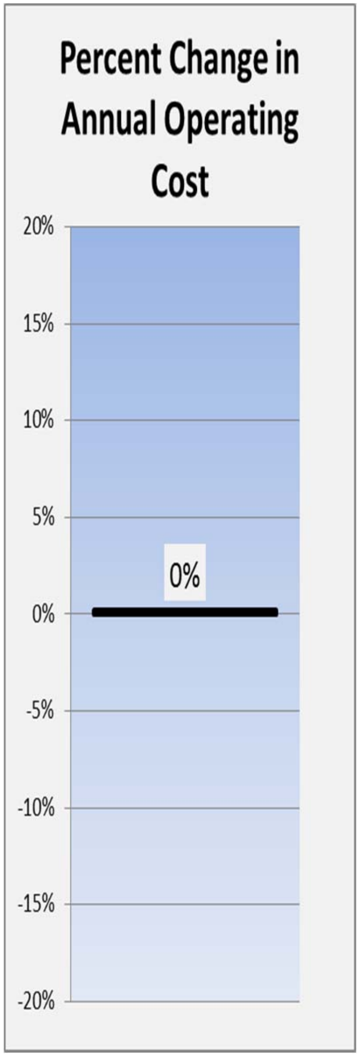


Cooling Tower Only System
Annual Water Use = 282,204 m^3

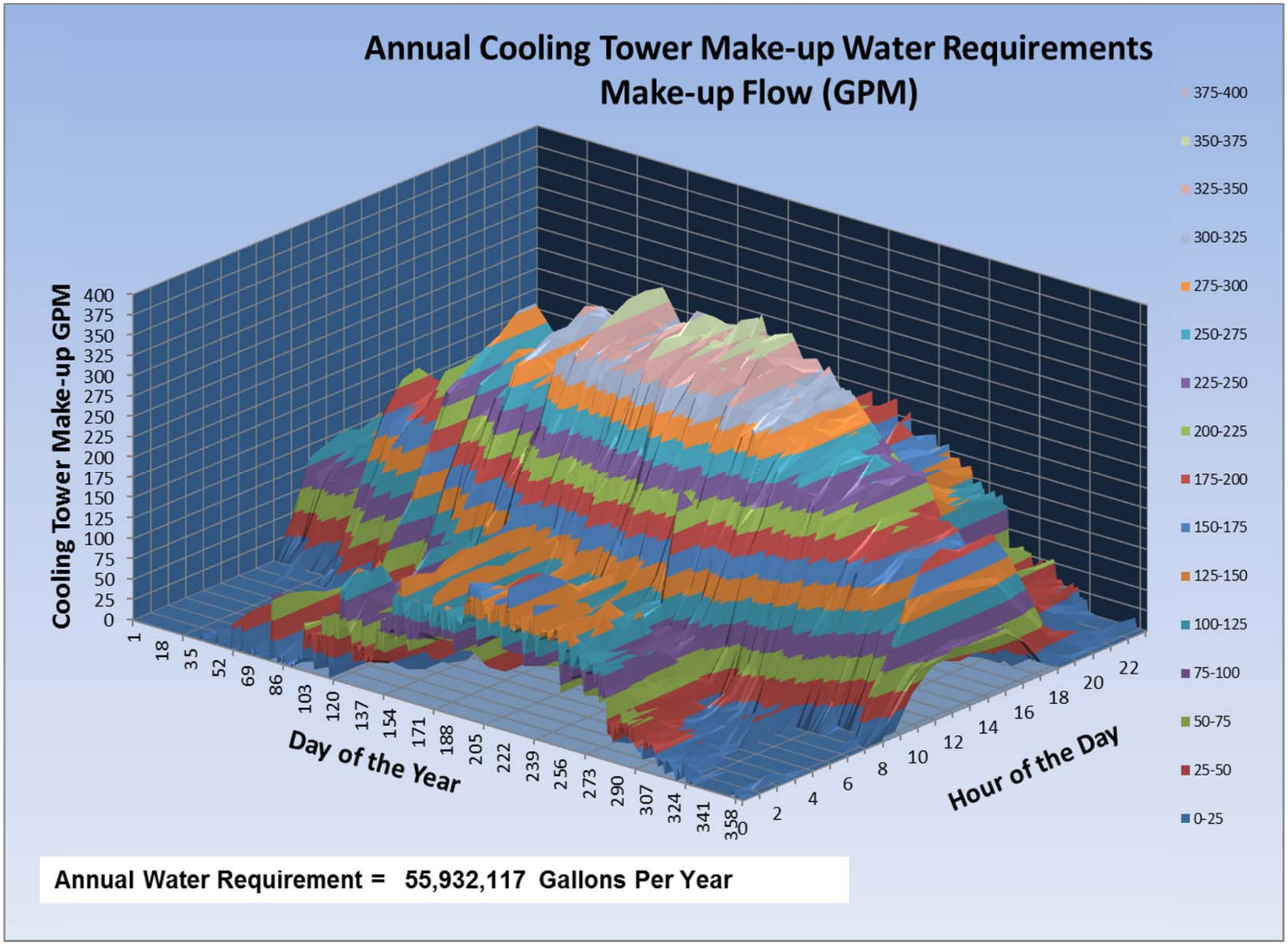
TCHS System 55% Savings
Annual Water Use = 127,359 m^3
Saving 154,845 m^3 / Year

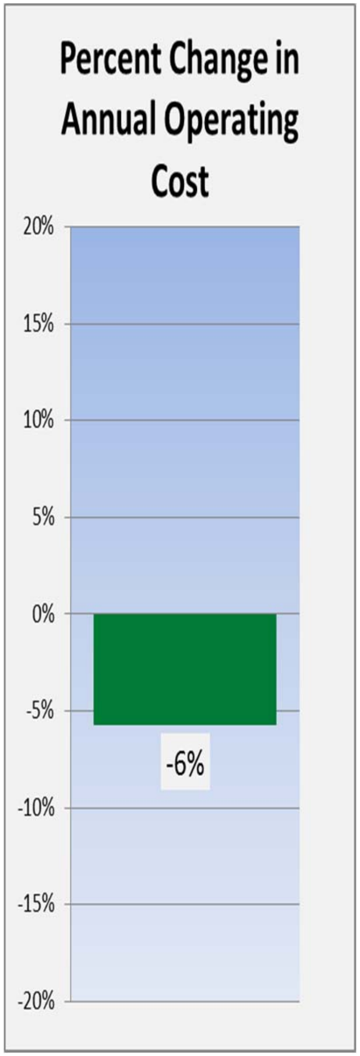
Cooling Tower Annual Make-up Water Requirements
Cooling Tower Only System



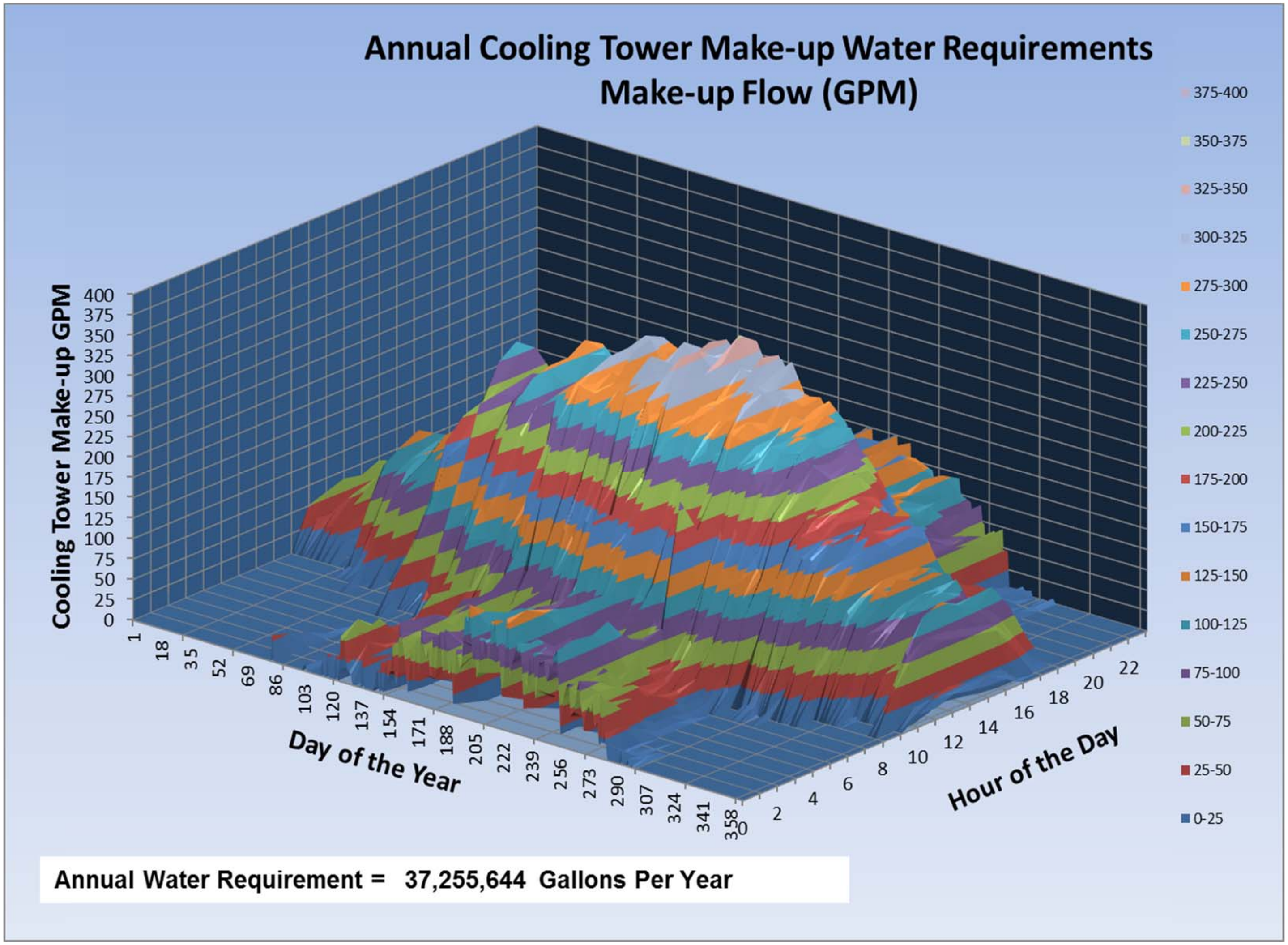


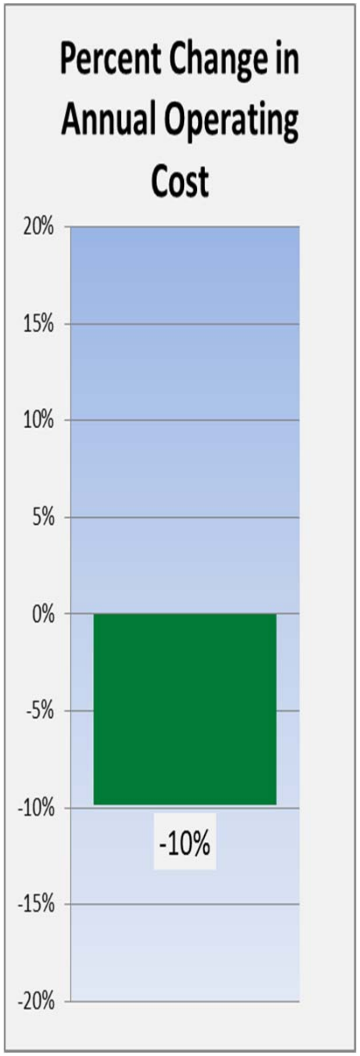
Cooling Tower Annual Make-up Water Requirements
25% Water Savings TSC Hybrid System





Cooling Tower Annual Make-up Water Requirements
50% Water Savings TSC Hybrid System





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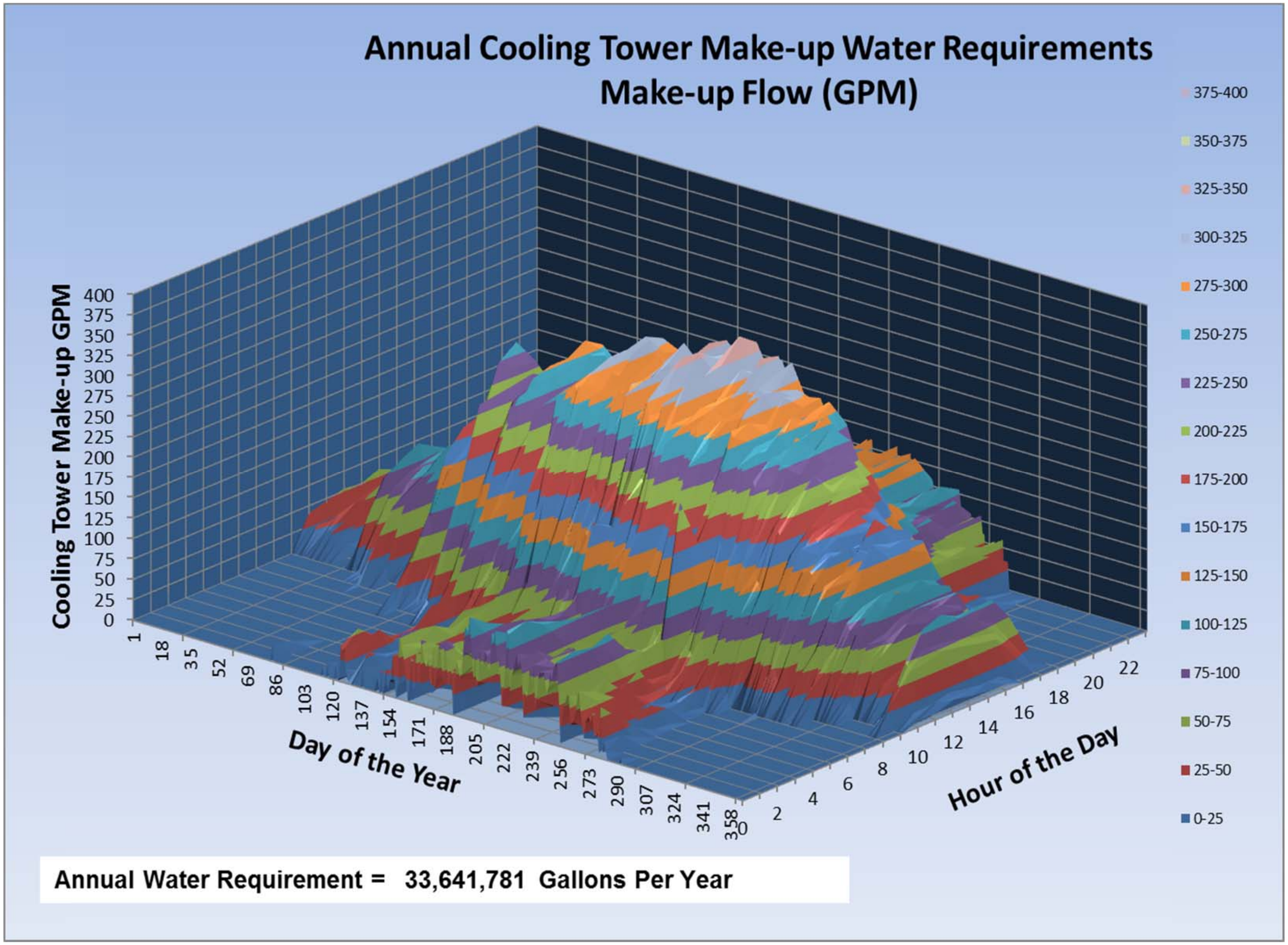
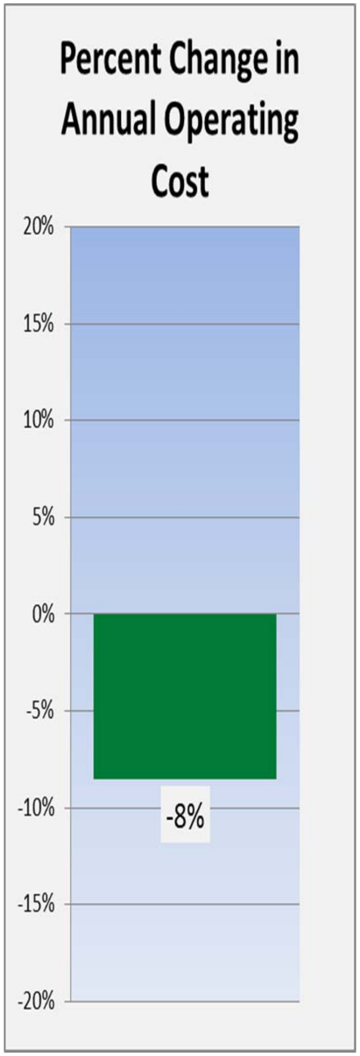
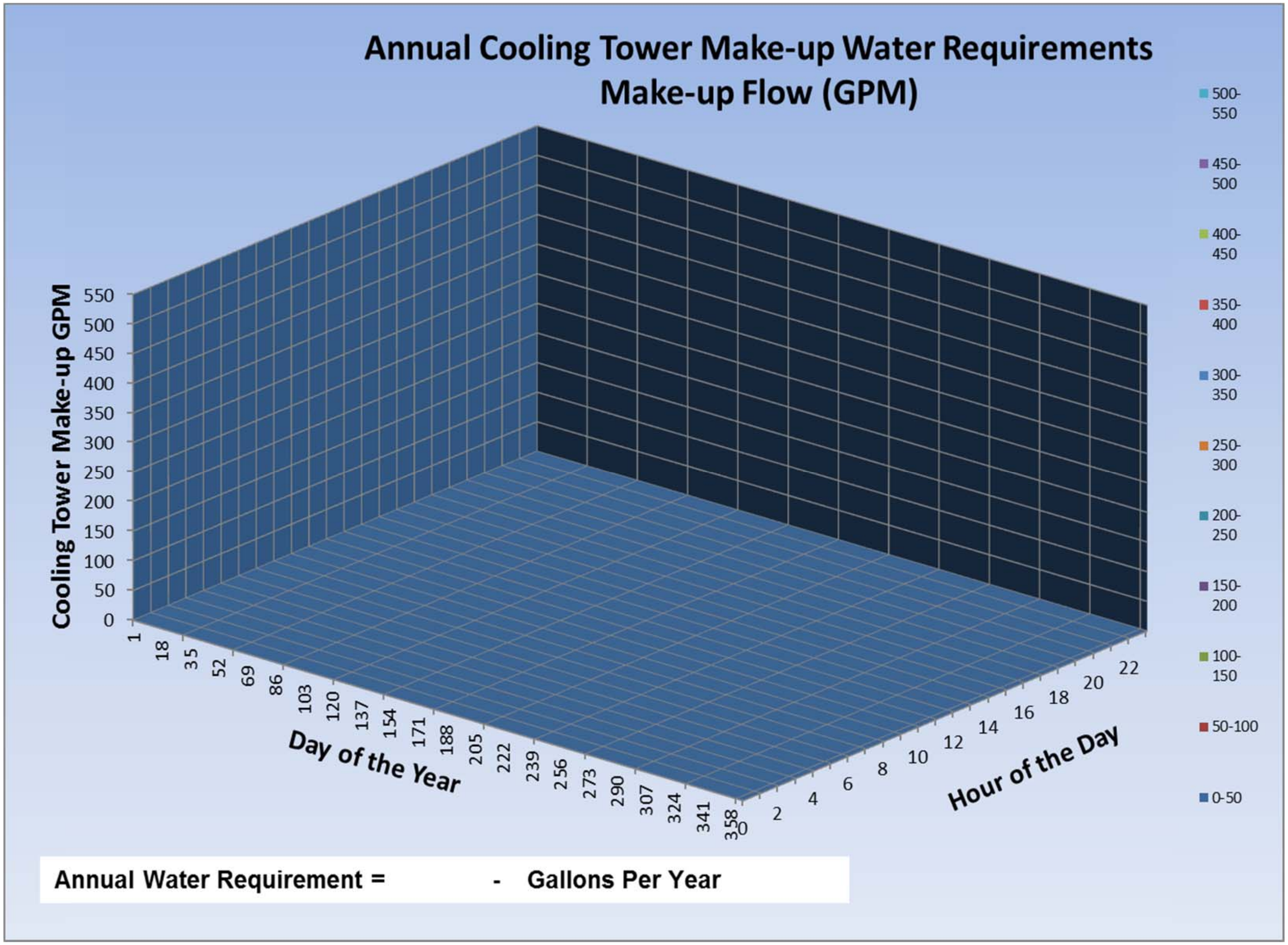
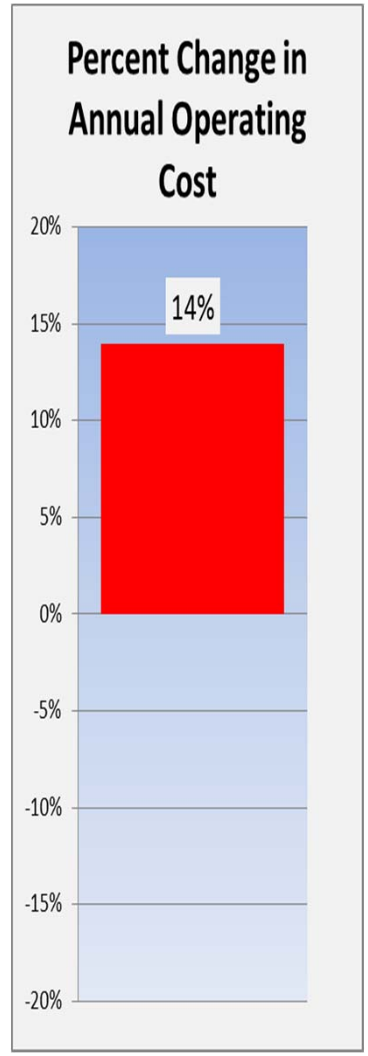
Cooling Tower Annual Make-up Water Requirements
55% Water Savings TSC Hybrid System





Cooling Tower Annual Make-up Water Requirements
Air Cooled Radiator System





Summary

- Concerns about the continuous assured availability and the escalating price of water are increasing

- If water is readily available and relatively inexpensive then evaporatively cooled water heat rejection systems provide the best system efficiencies

- Air-cooled heat rejection systems allow for zero water use but significantly increase both the annual average kWh and peak system kW

- Between these two traditional design choices exists a range of hybrid systems that offer significant water savings while minimizing the impact on energy

- The series flow dry sensible / wet cooling tower hybrid system allows for significant water savings while preserving the first cost and efficiency benefits of the open cooling tower