



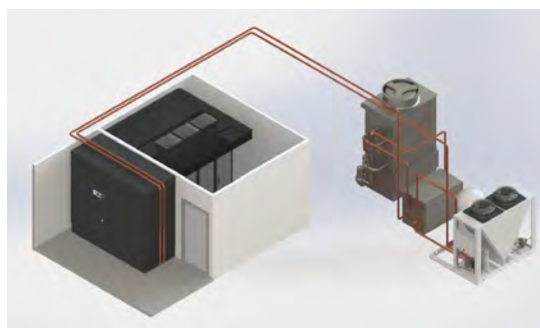


STULZ Water-Side Economizer Solutions

with STULZ Dynamic Economizer Cooling

Optimized Cap-Ex and Minimized Op-Ex

STULZ Data Center Design Guide

Author: Jason Derrick PE

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STULZ Water-Side Economizer
with STULZ Dynamic Economizer Cooling

- Optimized Cap-Ex
- Lowest Op-Ex

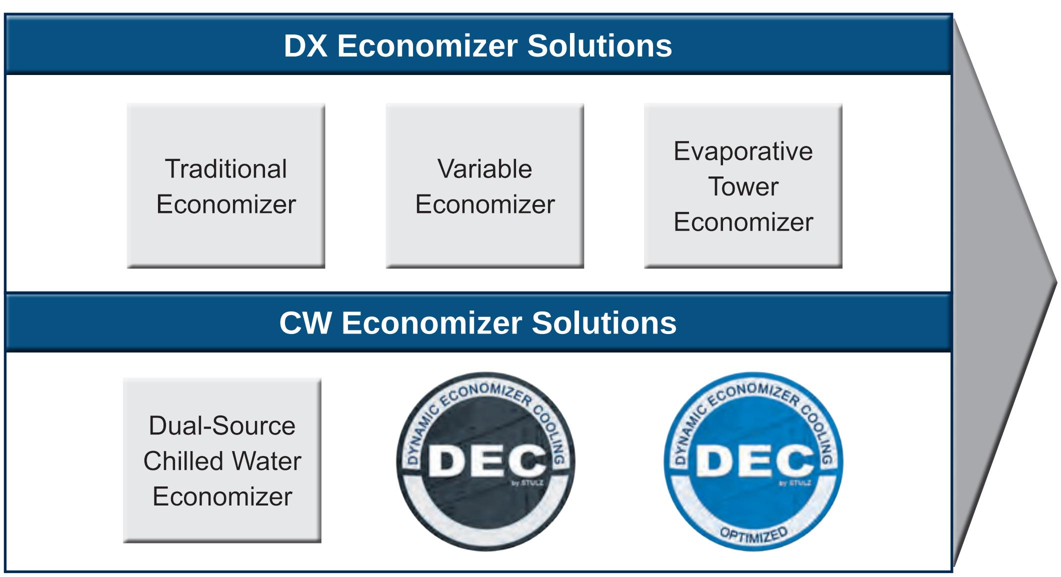
Technology Leader

STULZ has the broadest line of precision cooling equipment in the industry, from outdoor cooling, to indoor cooling, to retrofit and conditioning. STULZ is leading the way in energy efficient cooling solutions in the data center environment. All STULZ products can be applied to the latest ASHRAE standards and guidelines and used in water-side economizer solutions.

Leading the Way

As a leading manufacturer of precision cooling equipment, STULZ is able to support state-of-the-art energy efficient water-side economizer cooling solutions for data center applications. This design guide will develop why economizers are necessary, illustrate various designs of economizers, and focus on the latest leading-edge solution of STULZ Dynamic Economizer Cooling – including controls, and provides hard data on the tremendous value and cost savings that can be achieved.

STULZ Story of Innovative Economizer Cooling:



STULZ provides industry leading DX and CW-based water-side economizer cooling solutions - detailed in this design guide. The state-of-the-art **"STULZ Dynamic Economizer Cooling"** solution represents an exciting new approach - with proven results.

Industry Standards

These standards are very important to the data center industry and are having a large impact on how data centers are being designed and operated.

ASHRAE TC 9.9 Recommendations

Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance - provides thermal guidelines for data processing environments. The 2011 guideline outlines changes for server inlet temperature and humidity.

These changes to server inlet temperatures, and the allowance for increased delta-T across the server equipment, offer an opportunity to raise the return air temperatures to the cooling equipment. The trend for maximum efficiency in the data center is to isolate the hot return air from the cold supply air preventing air mixing.

What Has Changed	Service Inlet Air Temperature	Moisture Content
2004 Recommended (old)	68-77.0°F DB	40% RH to 55% RH
2011 Recommended (new)	64-80.6°F DB	41.9°F DP to 60% RH & 59°F DP
2011 Allowable (A1)	59-89.6°F DB	20-80% RH up to 62.1°F DP

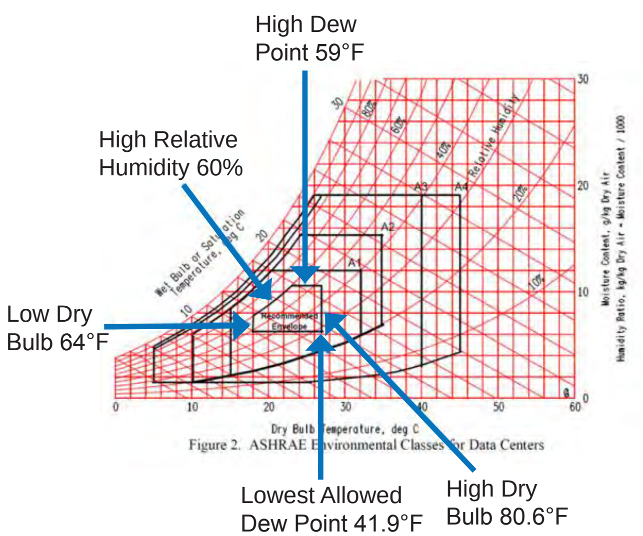


Figure 2. ASHRAE Environmental Classes for Data Centers

The opportunity is to raise the delta-T between the supply air temperature from the cooling equipment to the IT equipment and the return air temperature from the IT equipment to the cooling equipment. This is achieved by implementing hot aisle / cold aisle orientation of racks and optimized with various rack containment strategies.

In hot aisle containment configurations (Figure 1), the raised floor is pressurized with cold air from the precision cooling units, which passes through perforated floor tiles, taken into the servers, heated and exhausted into the contained hot aisle, directed back to the ceiling plenum, then returned to the CRAH units.

Perimeter Cooling w/raised floor and hot-aisle containment

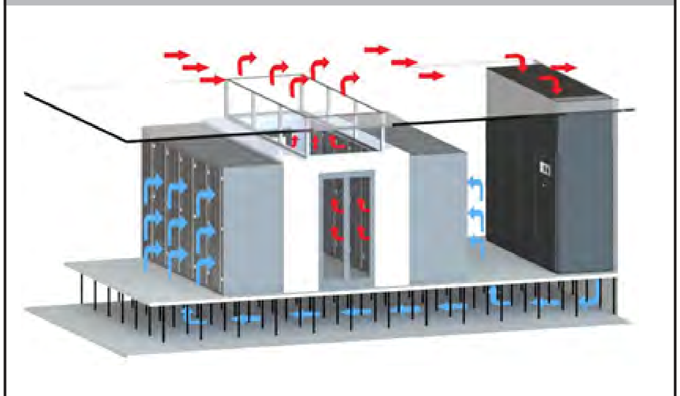


Figure 1

An alternate form of containment (Figure 2), is to utilize server racks that have a top ducted chimney connection. A CRAH with front discharge floods the space with cold air, allowing the servers to take cold air in from the front and discharge hot air out to the chimney. This hot air is discharged into a return duct or ceiling plenum and returned to the CRAH unit.

Perimeter Cooling w/slab floor and rack-containment

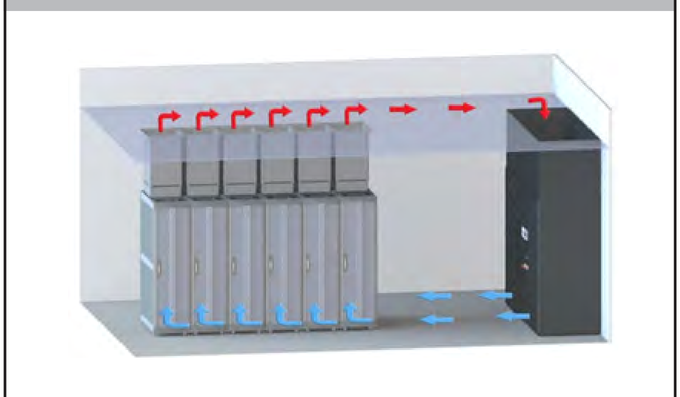


Figure 2

Higher return air temperature to the CRAC/CRAH equipment increases cooling efficiencies, as illustrated in the coil calculation on page 6.

Coil Calculations based on different design conditions to achieve different system optimizations:

CFD-230-C CRAH	Selection 1	Selection 2	Selection 3	Selection 4
Entering Air DB (°F)	75	95	95	95
Entering Air WB (°F)	61.1	67.8	67.8	67.8
Coil Leaving Air DB (°F)	51.0	54.1	54.2	69.9
Coil Leaving Air WB (°F)	50.5	53.1	53.1	59.2
Gross Total Capacity (BTU/H)	513,800	755,700	503,400	464,800
Gross Sensible Capacity (BTU/H)	461,200	755,700	503,400	464,800
Net Total Capacity (BTU/H)	493,800	735,700	494,500	444,800
Net Sensible Capacity (BTH/H)	441,200	735,700	494,500	444,800
Air Flow (ACFM)	18,000	18,000	12,000	18,000
External Static Pressure (in)	0.30	0.30	0.30	0.30
Altitude (ft)	0	0	0	0
Entering Fluid Temperature (°F)	45	45	45	55
Fluid Type	Water	Water	Water	Water
Percent Glycol (%)	0	0	0	0
Fluid Flow (GPM)	105	105	52	43
Leaving Fluid Temperature (°F)	55	59.7	64.7	77.1
Coil Fluid Pressure Drop (FT-H_2O)	10.2	10.2	2.7	1.9
Unit Fluid Pressure Drop (FT-H_2O)	23.3	23.3	8.6	7.0
Estimated Unit Power (kW)	**5.3**	**5.3**	**2.6**	**5.3**

Baseline

Selection 1

Shows a baseline standard unit selection for a CRAH, using standard conditions of 75°F entering air, a 52.2°F dew point, entering water of 45°F and leaving water temperature of 55°F.

Improved Net Sensible Capacity

Selection 2

+66%

Shows that an elevated return of 95°F at the same 52.2°F dew point and the same 105 GPM as the baseline selection provides an increase in capacity of **66%**.

Reduced Unit Power Consumption

Selection 3

-51%

Shows that an elevated return of 95°F at the same 52.2°F dew point and reduced airflow from 18,000 CFM to 12,000 CFM provides the same or better net sensible capacity as the baseline selection, and a reduction in unit power consumption of **51%,** and lowers the pump power required.

Increased Chiller Efficiency

Selection 4

+22%

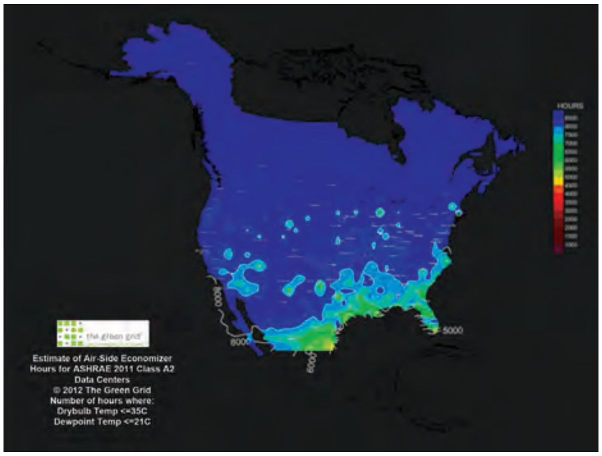
Shows that an elevated return of 95°F at the same 52.2°F dew point and increasing the entering water temperature from 45°F to 55°F provides the same or better net sensible capacity as the baseline selection, and increases the efficiency of chiller operation by more than **22%,** and lowers the pump power required.

Additional Benefits

By simply raising the air temperature entering the CRAH, tremendous benefits in efficiency can be accomplished. The scenarios shown can be mixed and matched to achieve optimal conditions. Results include more economizer hours, lower PUE, and lower energy costs.

ASHRAE 90.1 Energy Efficiency Standard

This Energy Efficiency Standard for Buildings - requires the use of air and water economizers in many locations to meet the prescriptive path. Since data centers have been identified to consume ~3% of the total energy consumed in the U.S., the former process cooling exemption was removed. Water-side economizers must meet 100% of the expected load with cooling towers when operating at or above 40°F dry bulb / 35°F wet bulb and with dry coolers when operating at or below 35°F dry bulb.



The DOE is mandating that all states adopt ASHRAE 90.1-2010, or a standard as stringent, for new data center design and construction by October 2013.

These changes to ASHRAE standards mean that we will have to rethink how data centers are designed.

The Evolution of Measuring Efficiency

The efficiency of comfort air conditioners is typically rated by the Energy Efficiency Ratio or EER, which is the ratio of cooling in British thermal units (BTU) to the energy consumed in watts (W), generally calculated using an outside temperature of 95°F and a return air tempeature of 80°F and 50% RH. While this is an appropriate metric for comfort cooling equipment, high sensible cooling equipment efficiency is measured using the sensible coefficient of performance (SCOP).

SCOP is a ratio calculated by dividing the net sensible cooling capacity in watts by the total power input in watts at any given set of rating conditions. The net sensible cooling capacity is the gross sensible capacity minus the energy dissipated into the cooled space by the fan system.

In this paper, STULZ is following ASHRAE 90.1 – 2010 guideline for SCOP.

Economizers are generally described as one of two types:

Air-Side Economizer

Direct free cooling is directly introducing outside air into the space to cool the space. The downside of this is the requirement of high levels of filtration and the potential introduction of sulfides an other air contaminates into the data center environment. This additional filtration requires the use of larger fan motors to move the required air to directly free cool the space. Another concern is humidity control.

When the air is cool enough to be used for economization, you still have a high percentage of time where the grains of moisture per pound are too low and require additional humidification. The solution is to either limit the outside air based on dew point, which will limit the economizer hours, or add additional humidification into the space, which could potentially offset the energy savings of being in economization mode of cooling.

STULZ offers direct and indirect air-side economizer cooling solutions with CW or DX mechanical cooling and/or direct or indirect adiabatic cooling.

Water-Side Economizer

Indirect free cooling can be achieved with a water/glycol fluid loop that is pumped through an external heat exchanger of some form, and then providing cooled fluid as a cooling medium to a water/glycol coil that absorbs heat from hot return air. This method is referred to as indirect because the intermediate fluid is contained in a closed system that is isolated from the data center white space. In this white paper, we illustrate how a water-side economizer can be used to achieve indirect free cooling.

There are several water-side economizer options that STULZ is able to support. Each of these designs can be integrated with STULZ indoor cooling (perimeter / ceiling) or STULZ outdoor cooling (air handler unit / modular container unit).

The focus of this design guide is the various methods of Water-Side Economizer Cooling, with an emphasis on Dynamic Economizer Cooling.

When elevating the return air temperature of a CRAC, both power consumption and SCOP are impacted. As is shown below the SCOP is increased as the return temperature is increased. Adding a traditional economizer reduces unit yearly power consumption, this power consumption reduction is further increased with the increase in return air temperature allowing for more available Free Cooling and Assist hours.

30 ton CRAC: 75°F 40% RH Return Air
Baltimore, MD

	CRAC with Constant Speed Pump and DryCooler				CRAC with Traditional Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hrs	% of Yr	Total kWh
Full Compressor Operation	53.0	8760	100%	463,930	55.7	5998	68%	333,789
Free Cooling Assist					39.2	1249	14%	48,923
Free Cooling					22.7	1513	17%	34,330
Yearly Total Unit Power Consumption (kWh)				463,930				417,042
SCOP				2.1				2.1

Savings Comparison

Total kWh Savings Per Year: 46,888

Total Cost Savings Per Year: $4,688

30 ton CRAC: 80°F 30% RH Return Air
Baltimore, MD

	CRAC with Constant Speed Pump and DryCooler				CRAC with Traditional Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hrs	% of Yr	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	55.9	5272	60%	294,652
Free Cooling Assist					39.3	1975	23%	77,598
Free Cooling					22.7	1513	17%	34,330
Yearly Total Unit Power Consumption (kWh)				466,120				406,580
SCOP				2.3				2.3

Savings Comparison

Total kWh Savings Per Year: 59,540

Total Cost Savings Per Year: $5,954

* 10¢ per kWh

Benefit of Increasing Return Air Temperature from **75°F 40% to 80°F 30%**

	CRAC with DryCooler	CRAC with Free Cooling
Power Savings	-0.5%	2.5%
SCOP Increase	9.5%	9.5%

- Based on 0.10 $/kWh
- Based on 0% glycol
- Full compressor operation includes compressors, fan, and pump

When elevating the return air temperature of a CRAH coupled to an air cooled chiller, power consumption is reduced. Further savings can be obtained by introducing a form of economizer into the system to allow for cooling without compressor operation. This is shown below with a Dual Coil CRAH with one circuit on an air cooled chiller and the other circuit on a closed loop cooling tower. Both the economizer system and non-economizer system consume less power at an elevated return temperature.

30 ton CRAH: 75°F 40% RH Return Air, 45°F Entering Water
Baltimore, MD

	CRAH Coupled to an Air Cooled Chiller				CRAH with Dual Coils Coupled to an Air Cooled Chiller & Coupled to an Evaporative Cooling Tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hrs	% of Yr	Total kWh
Air Cooled Chiller Operation	46.2	8760	100%	404,362	47.0	6638	76%	311,654
Evaporative Cooling Tower Operation				-	11.3	2122	24%	23,936
Yearly Total Unit Power Consumption (kWh)				404,362	-	-	-	335,590

Savings Comparison

Total kWh Savings Per Year: 68,771

Total Cost Savings Per Year: $6,877

30 ton CRAH: 80°F 30% RH Return Air, 50°F Entering Water
Baltimore, MD

	CRAH Coupled to an Air Cooled Chiller				CRAH with Dual Coils Coupled to an Air Cooled Chiller & Coupled to an Evaporative Cooling Tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hrs	% of Yr	Total kWh
Air Cooled Chiller Operation	43.1	8760	100%	377,556	46.3	6245	71%	289,144
Evaporative Cooling Tower Operation				-	10.3	2515	29%	25,804
Yearly Total Unit Power Consumption (kWh)				377,556	-	-	-	314,974

Savings Comparison

Total kWh Savings Per Year: 62,609

Total Cost Savings Per Year: $6,261

* 10¢ per kWh

Benefit of Increasing Return Air Temperature from **75°F 40% to 80°F 30%**

Power Savings for CRAH	Power Savings for CRAH with Dual Coil
7.1%	6.1%

- Based on 0.10 $/kWh
- Pump is 65% efficient
- 1.23 kW per ton Air-Cooled Chiller
- Based on 0% glycol

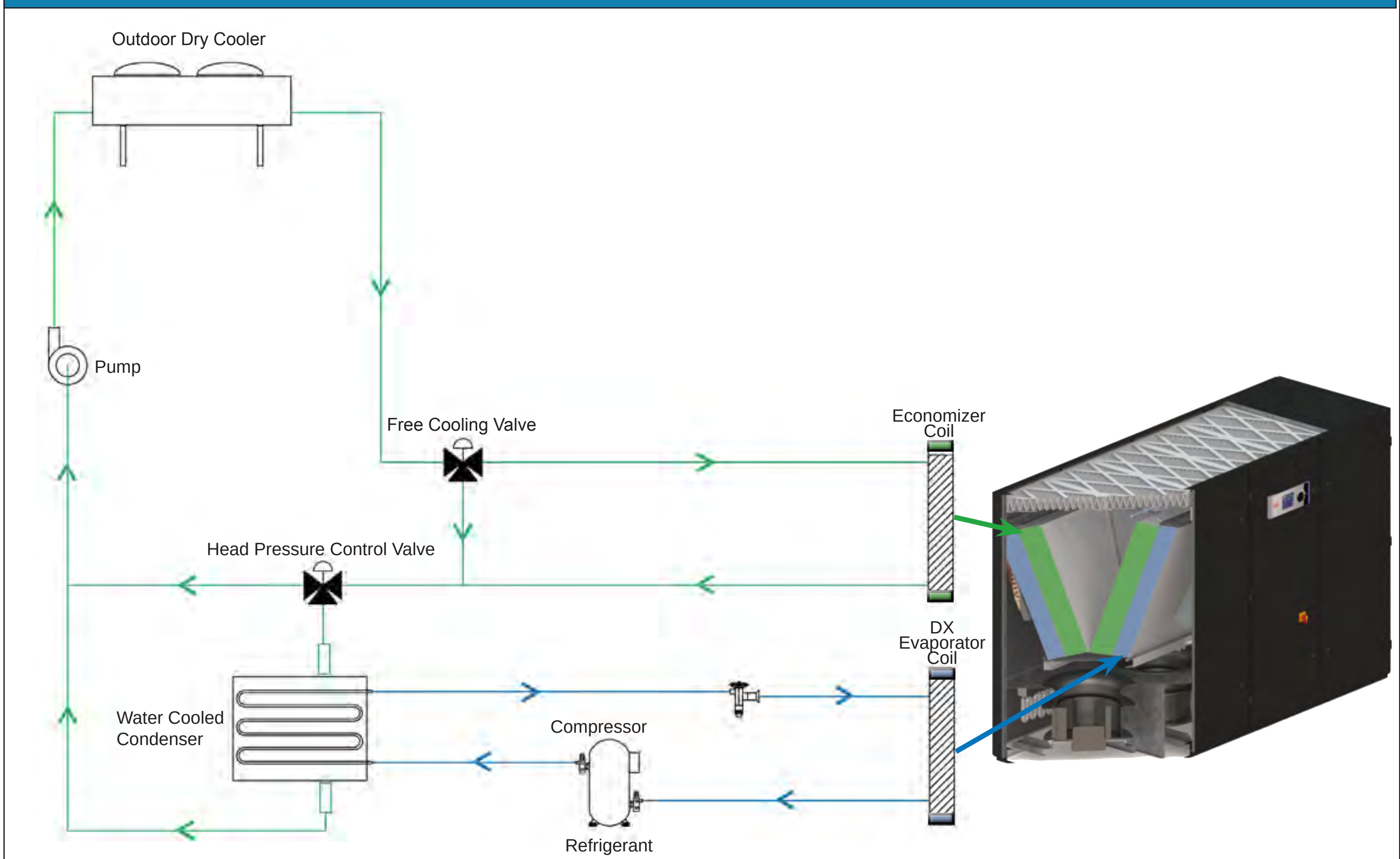
STULZ DX CRAC with Economizer Coil and Condenser Loop

A standard CRAC cooling unit with water-side economizer capability consists of a CRAC with a direct expansion (DX) coil and a chilled water / glycol coil.

When the fluid temperature is warm, the unit operates as a fluid cooled DX unit, rejecting the heat into a heat rejection device (dry cooler or closed loop cooling tower).

When ambient temperature drops, the flow of the resulting lower temperature fluid is diverted into the water / glycol coil, providing a cooling assist mode of operation.

As temperature continues to drop, the required data center cooling capacity can be satisfied using only the cooling fluid, then the CRAC will turn off its compressors and only cool using the water / glycol loop.



STULZ is currently using highly efficient scroll compressors with available tandem and stepped capacity in 1, 2, 3, or 4 stages of operation, each with a hot-gas bypass option. Following is a table that illustrates how this highly effective means of DX cooling works:

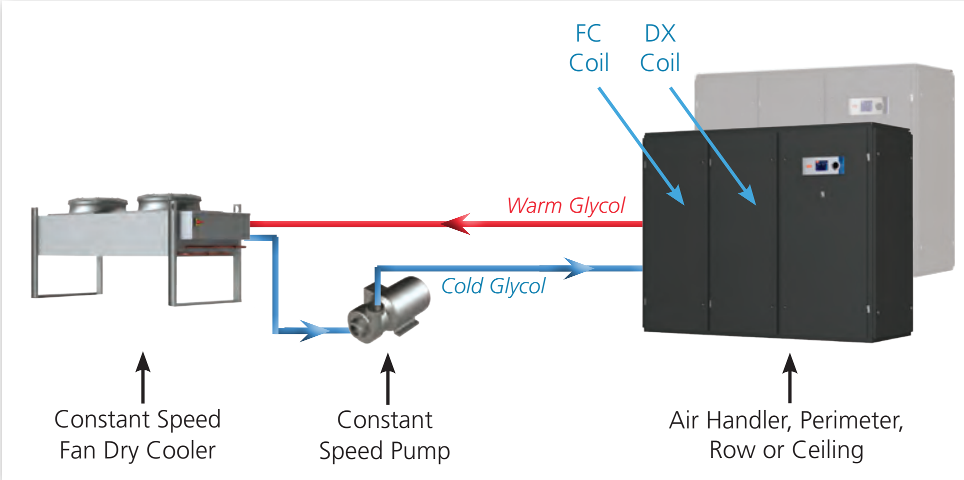
Capacity	Tandem Compressor		Compressor
	1a	1b	2
25%	X		
50%			X
75%		X	X
100%	X	X	X

Used with the following STULZ Water-Side Economizers:

- Traditional Economizer Cooling
- Variable Economizer Cooling
- Evaporative Tower Economizer Cooling

Traditional Economizer Cooling

Traditional Economizer Cooling is comprised of a constant fan speed dry cooler (with fans being cycled on and off based on fluid temperature), constant speed pumps, and water/glycol cooled free cooling CRACs (consisting of both a DX cooling coil and a water/glycol free cooling coil).



30 ton CRAC with FC Coil - 80°F 30% RH Return Air

Baltimore MD

	CRAC with Constant Speed Pump and DryCooler				CRAC with Free Cooling Coupled with Constant Speed Pump and DryCooler			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	55.9	5272	60%	294,652
Free Cooling Assist				-	39.3	1975	23%	77,598
Free Cooling				-	22.7	1513	17%	34,330
Yearly Total Unit Power Consumption (kWh)				**466,120**	-	-	-	**406,580**

Total kWh Savings Per Year: 59,540

Total Cost Savings Per Year: $5,954

Salt Lake City, UT (calculated at 4,500 ft altitude)

	CRAC with Constant Speed Pump and DryCooler				CRAC with Free Cooling Coupled with Constant Speed Pump and DryCooler			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Full Compressor Operation	54.6	8760	100%	478,603	57.3	4491	51%	257,402
Free Cooling Assist				-	40.7	2369	27%	96,454
Free Cooling				-	24.1	1900	22%	45,819
Yearly Total Unit Power Consumption (kWh)				**478,603**	-	-	-	**399,674**

Total kWh Savings Per Year: 78,929

Total Cost Savings Per Year: $7,892

Portland, OR

	CRAC with Constant Speed Pump and DryCooler				CRAC with Free Cooling Coupled with Constant Speed Pump and DryCooler			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	55.2	4953	57%	273,455
Free Cooling Assist				-	39.3	3298	38%	129,578
Free Cooling				-	22.7	509	6%	11,549
Yearly Total Unit Power Consumption (kWh)				**466,120**	-	-	-	**414,583**

Total kWh Savings Per Year: 51,537

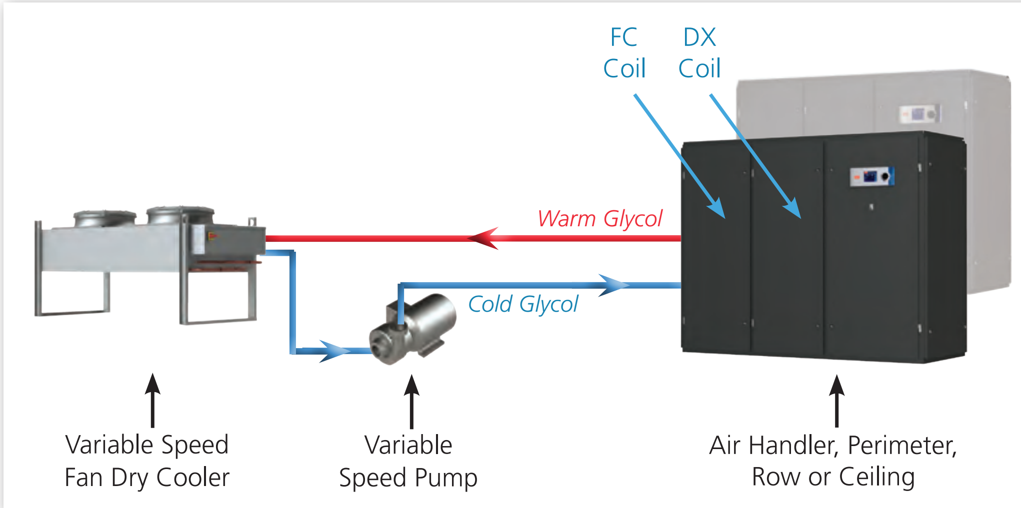
Total Cost Savings Per Year: $5,153

* 10¢ per kWh

- Using a nominal Drycooler
- Using Pump Power for CRAC and Drycooler Pressure Drop
- Pump is 65% efficient
- Full compressor operation includes compressors, fan, and pump
- Based on 0% glycol

Variable Economizer Cooling

Variable Economizer Cooling is comprised of a variable fan speed dry cooler (with fan speed controlled based on fluid temperature), variable speed pumps (controlled based on fluid pressure), and water/glycol cooled free cooling CRACs (consisting of both a DX and a water/glycol free cooling coil).



30 ton CRAC with FC Coil: 80°F 30% RH Return Air

Baltimore, MD

	CRAC with Constant Speed Pump and DryCooler				CRAC with Free Cooling Coupled with Variable Speed Pump and DryCooler			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	44.4	5557	63%	246,534
Free Cooling Assist				-	28.8	2080	24%	59,915
Free Cooling				-	15.1	1123	13%	17,028
Yearly Total Unit Power Consumption (kWh)				**466,120**	-	-	-	**323,476**

Total kWh Savings Per Year: 142,644

Total Cost Savings Per Year: $14,264

Salt Lake City, UT (calculated at 4,500 ft altitude)

	CRAC with Constant Speed Pump and DryCooler				CRAC with Free Cooling Coupled with Variable Speed Pump and DryCooler			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Full Compressor Operation	54.6	8760	100%	478,603	46.0	4777	55%	219,601
Free Cooling Assist				-	30.5	2571	29%	78,437
Free Cooling				-	17.1	1412	16%	24,219
Yearly Total Unit Power Consumption (kWh)				**478,603**	-	-	-	**322,258**

Total kWh Savings Per Year: 156,345

Total Cost Savings Per Year: $15,634

Portland, OR

	CRAC with Constant Speed Pump and DryCooler				CRAC with Free Cooling Coupled with Variable Speed Pump and DryCooler			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	44.2	5243	60%	232,018
Free Cooling Assist				-	29.3	3239	37%	94,844
Free Cooling				-	18.5	278	3%	5,150
Yearly Total Unit Power Consumption (kWh)				**466,120**	-	-	-	**332,012**

Total kWh Savings Per Year: 134,108

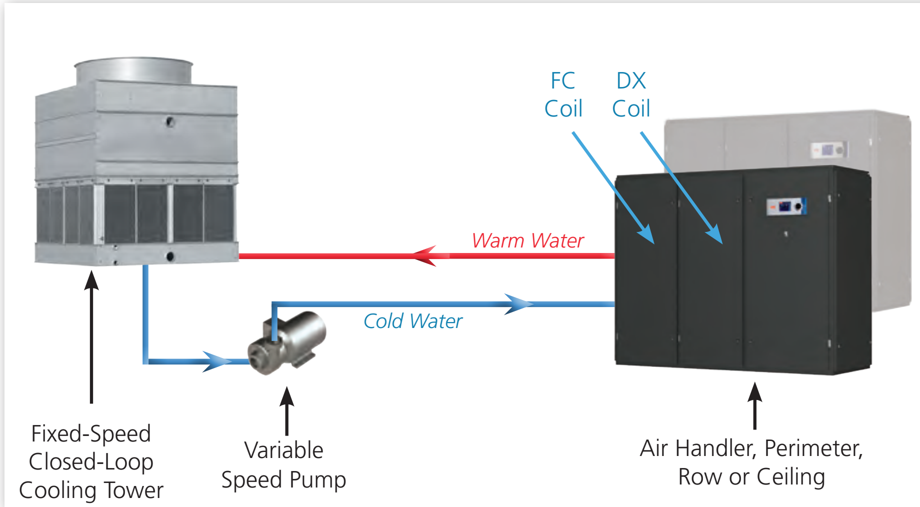
Total Cost Savings Per Year: $13,410

- Nominal 30 ton Drycooler
- Using Pump Power for CRAC and Drycooler Pressure Drop
- Pump is 65% efficient
- Full compressor operation includes compressors, fan, and pump
- Based on 0% glycol
- kW average shown as actual kW varies over ambient range

* 10¢ per kWh

Evaporative Tower Economizer Cooling

Evaporative Tower Economizer Cooling is comprised of a closed loop evaporative cooling tower (fan speed controlled based on fluid temperature), a constant speed pump, and water/glycol cooled free cooling CRACs (consisting of both a DX and a water/glycol free cooling coil).



30 ton CRAC with FC Coil: 80°F 30% RH Return Air

Baltimore, MD

	CRAC with Constant Speed Pump and DryCooler				CRAC with free cooling coupled with fixed-speed closed loop cooling tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	47.3	5028	57%	237,774
Free Cooling Assist				-	30.7	1610	18%	49,411
Free Cooling				-	14.1	2122	24%	29,899
Yearly Total Unit Power Consumption (kWh)				**466,120**	-	-	-	**317,084**

Total kWh Savings Per Year: 149,036

Total Cost Savings Per Year: $14,904

Salt Lake City, UT (calculated at 4,500 ft altitude)

	CRAC with Constant Speed Pump and DryCooler				CRAC with free cooling coupled with fixed-speed closed loop cooling tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Full Compressor Operation	54.6	8760	100%	478,603	49.4	3810	43%	188,271
Free Cooling Assist				-	32.8	2293	26%	75,245
Free Cooling				-	16.2	2657	30%	43,083
Yearly Total Unit Power Consumption (kWh)				**478,603**	-	-	-	**306,599**

Total kWh Savings Per Year: 172,003

Total Cost Savings Per Year: $17,200

Portland, OR

	CRAC with Constant Speed Pump and DryCooler				CRAC with free cooling coupled with fixed-speed closed loop cooling tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Full Compressor Operation	53.2	8760	100%	466,120	47.3	6539	75%	309,229
Free Cooling Assist				-	30.7	956	11%	29,340
Free Cooling				-	14.1	1265	14%	17,824
Yearly Total Unit Power Consumption (kWh)				**466,120**	-	-	-	**356,393**

Total kWh Savings Per Year: 109,727

Total Cost Savings Per Year: $10,973

- Nominal 30 ton Cooling Tower
- Using Pump Power for CRAC and Water Tower Pressure Drop
- Pump is 65% efficient
- Full compressor operation includes compressors, fan, and pump
- Based on 0% glycol

* 10¢ per kWh

Comparison of DX Economizer Cooling

30 ton CRAC with FC Coil: 80°F 30% RH Return Air

		CRAC with Constant Speed Pump & DryCooler	Traditional Economizer Cooling	Variable Economizer Cooling	Evaporative Tower Economizer Cooling
Baltimore MD	System kWh Per Yr	466,120	406,580	323,476	317,084
	System Operational Cost Per Yr	$46,612	$40,658	$32,348	$31,708
	% Energy Savings (kWh Per Yr & Associated Operational Cost Per Yr)		13%	31%	32%
Salt Lake City UT	System kWh Per Yr	478,603	399,674	322,258	306,599
	System Operational Cost Per Yr	$47,860	$39,967	$32,225	$30,660
	% Energy Savings (kWh Per Yr & Associated Operational Cost Per Yr)		17%	33%	36%
Portland OR	System kWh Per Yr	466,120	414,583	332,012	356,393
	System Operational Cost Per Yr	$46,612	$41,458	$33,201	$35,639
	% Energy Savings (kWh Per Yr & Associated Operational Cost Per Yr)		11%	29%	24%

- Power Cost $0.10 per kWh
- Indoor conditions are 80/30%

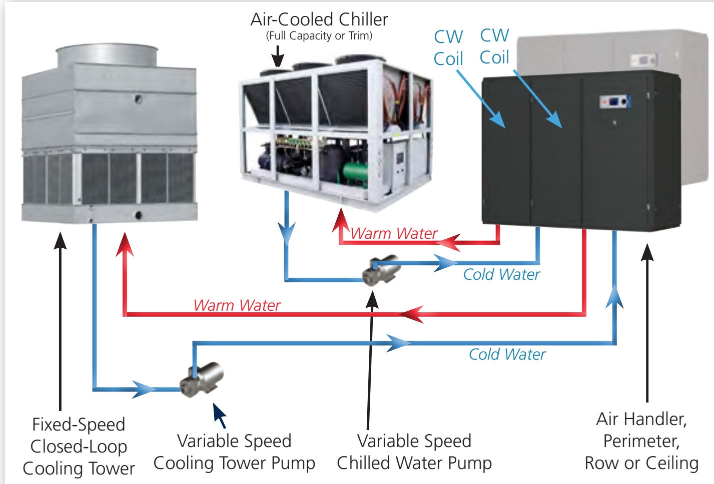
Summary: Various DX-based economizer solutions display how different economizer systems compare with one another and how effective each solution is in different Climate Regions. A further analysis of return on investment (ROI) is provided in Appendix A.

STULZ Water-Side Economizers based on a CRAH with Single or Dual Circuit

Dual-Source Chilled Water Economizer Cooling

Dual-Source Chilled Water Economizer Cooling is comprised of an evaporative cooling tower (controlled based on fluid temperature), cooling tower pumps, chiller (controlled based on fluid temperature), chiller pumps, and a CRAH unit (with dual circuited interlaced chilled water cooling coil).

The solution data is based on operating only one circuit at a time.



30 ton CRAH: 80°F 30% RH Return Air, 50°F Entering

Baltimore, MD

	CRAH Coupled with Air-Cooled Chiller				CRAH with Dual Coils Coupled with Air-Cooled Chiller and Evaporative Cooling Tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Air Cooled Chiller Operation	43.1	8760	100%	377,556	46.3	6245	71%	289,144
Evaporative Cooling Tower Operation				-	10.3	2515	29%	25,804
Yearly Total Unit Power Consumption (kWh)				**377,556**	-	-	-	**314,947**

Total kWh Savings Per Year: 62,609

Total Cost Savings Per Year: $6,261

Salt Lake City, UT (calculated at 4,500 ft altitude)

	CRAH Coupled with Air-Cooled Chiller				CRAH with Dual Coils Coupled with Air-Cooled Chiller and Evaporative Cooling Tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Air Cooled Chiller Operation	44.0	8760	100%	385,440	47.0	5624	64%	264,328
Evaporative Cooling Tower Operation				-	11.1	3136	36%	34,810
Yearly Total Unit Power Consumption (kWh)				**385,440**	-	-	-	**299,138**

Total kWh Savings Per Year: 86,302

Total Cost Savings Per Year: $8,630

Portland, OR

	CRAH Coupled with Air-Cooled Chiller				CRAH with Dual Coils Coupled with Air-Cooled Chiller and Evaporative Cooling Tower			
Mode	kW	Hrs	% of Yr	Total kWh	kW	Hours	% of Year	Total kWh
Air Cooled Chiller Operation	43.1	8760	100%	377,556	46.3	7357	84%	340,629
Evaporative Cooling Tower Operation				-	10.3	1403	16%	14,395
Yearly Total Unit Power Consumption (kWh)				**377,556**	-	-	-	**355,024**

Total kWh Savings Per Year: 22,532

Total Cost Savings Per Year: $2,253

- Pump is 65% efficient
- Chiller power is assumed as 1.23kW per ton
- Nominal 30 ton Chiller
- Nominal 30 ton Cooling Tower
- Based on 0% glycol

* 10¢ per kWh

STULZ Dynamic Economizer Cooling

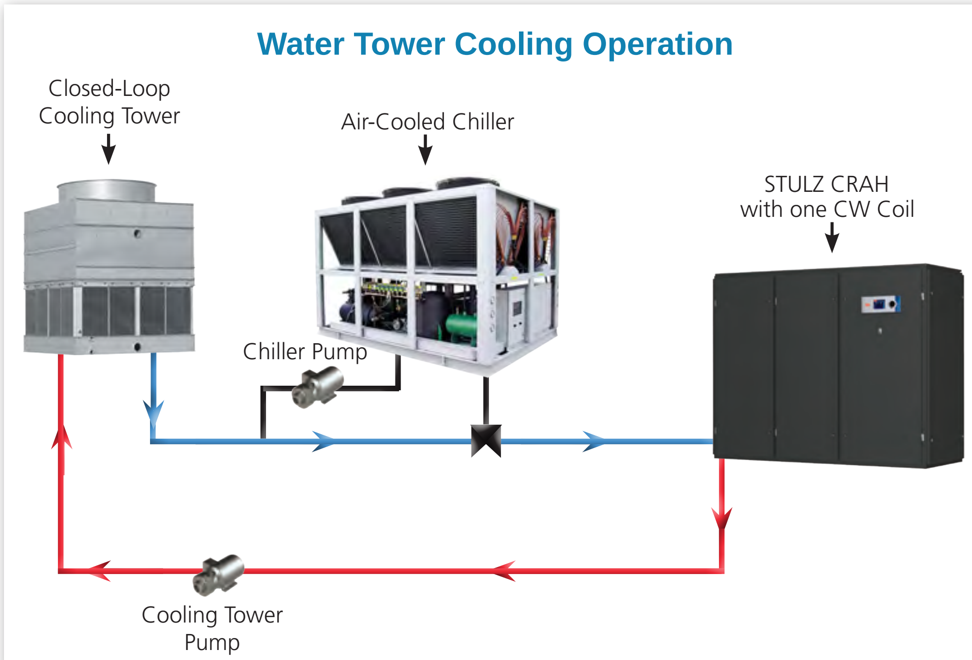
STULZ Dynamic Economizer Cooling (DEC) is a state-of-the-art water-side economizer solution, and is comprised of an evaporative cooling tower, cooling tower pump, chiller, chiller pump, control mixing valves, and chilled water CRAHs.

STULZ DEC is designed to provide maximum system economization, which provides minimal operational cost. This is achieved by increasing cooling tower run hours and minimizes chiller operation.

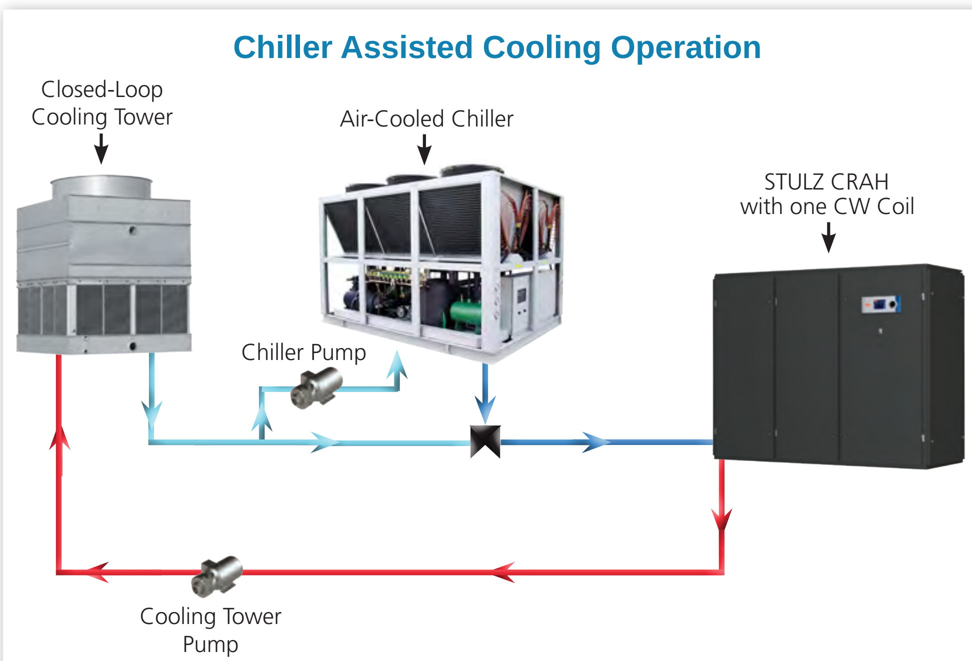
Water Tower Cooling Mode and Chiller Assisted Cooling Mode

Water Tower Cooling Mode and Chiller Assisted Cooling Mode

When ambient conditions are near or below required cooling fluid temperature, the Chiller Assisted Cooling system operates in the cooling tower mode, providing cooling without energizing the chiller.



If ambient temperature increases above the required cooling fluid temperature some flow from the tower is diverted to the chiller to provide the trim needed to maintain the cooling fluid temperature. This system is designed to minimize the hours of chiller operation and optimize opportunity for economization.



30 ton CRAH: 80°F 30% RH Return Air, 50°F Entering Water

Baltimore, MD

	CRAH Coupled with Air-Cooled Chiller				STULZ Dynamic Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Chiller	43.1	8760	100%	377,556	43.8	4107	47%	179,895
Chiller Assist				-	24.5	2711	31%	66,364
Wet Tower				-	11.1	1135	13%	12,575
Dry Tower				-	9.5	807	9%	7700
Yearly Total Unit Power Consumption (kWh)				**377,556**	-	-	-	**266,534**

Total kWh Savings Per Year: 111,022

Total Cost Savings Per Year: $11,102

Salt Lake City, UT (calculated at 4,500 ft altitude)

	CRAH Coupled with Air-Cooled Chiller				STULZ Dynamic Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Chiller	44.0	8760	100%	385,440	44.7	3268	37%	146,077
Chiller Assist				-	23.3	3527	40%	82,259
Wet Tower				-	12.6	1038	12%	13,062
Dry Tower				-	11.0	927	11%	10,209
Yearly Total Unit Power Consumption (kWh)				**385,440**	-	-	-	**251,607**

Total kWh Savings Per Year: 133,833

Total Cost Savings Per Year: $13,383

Portland, OR

	CRAH Coupled with Air-Cooled Chiller				STULZ Dynamic Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Chiller	43.1	8760	100%	377,556	43.7	3362	38%	146,952
Chiller Assist				-	22.8	5098	58%	116,299
Wet Tower				-	11.5	262	3%	3001
Dry Tower				-	10.2	38	0.4%	388
Yearly Total Unit Power Consumption (kWh)				**377,556**	-	-	-	**266,640**

Total kWh Savings Per Year: 110,916

Total Cost Savings Per Year: $11,092

- Pump is 65% efficient
- Chiller power is assumed as 1.23kW per ton
- Nominal 30 ton Chiller
- Nominal 30 ton Cooling Tower
- Based on 0% glycol
- kW average shown as actual kW varies over ambient range

* 10¢ per kWh

Summary: The STULZ Dynamic Economizer Cooling Solution provides improved energy efficiency at a return temperature of 80°F and an entering water temperature of 50°F; however, the system efficiency can be optimized further by elevating the return air temperature and utilizing warm water cooling.

Comparison of Chilled Water Economizer Cooling

30 ton CRAH: 80°F 30% RH Return Air, 50°F Entering Air / 60°F Leaving Water

		CRAH Coupled with Air Cooled Chiller	CRAH with Dual Coils Coupled with an Air Cooled Chiller & Evaporative Cooling Tower	**STULZ Dynamic Economizer Cooling**
Baltimore MD	System kWh Per Yr	377,556	314,947	266,534
	System Operational Cost Per Yr	$37,757	$31,495	$26,653
% Energy Savings (kWh Per Yr & Associated Operational Cost Per Yr)			17%	29%
Salt Lake City UT	System kWh Per Yr	385,440	299,138	251,607
	System Operational Cost Per Yr	$38,544	$29,914	$25,161
% Energy Savings (kWh Per Yr & Associated Operational Cost Per Yr)			22%	35%
Portland OR	System kWh Per Yr	377,556	355,024	266,640
	System Operational Cost Per Yr	$37,756	$35,502	$26,664
% Energy Savings (kWh Per Yr & Associated Operational Cost Per Yr)			6%	29%

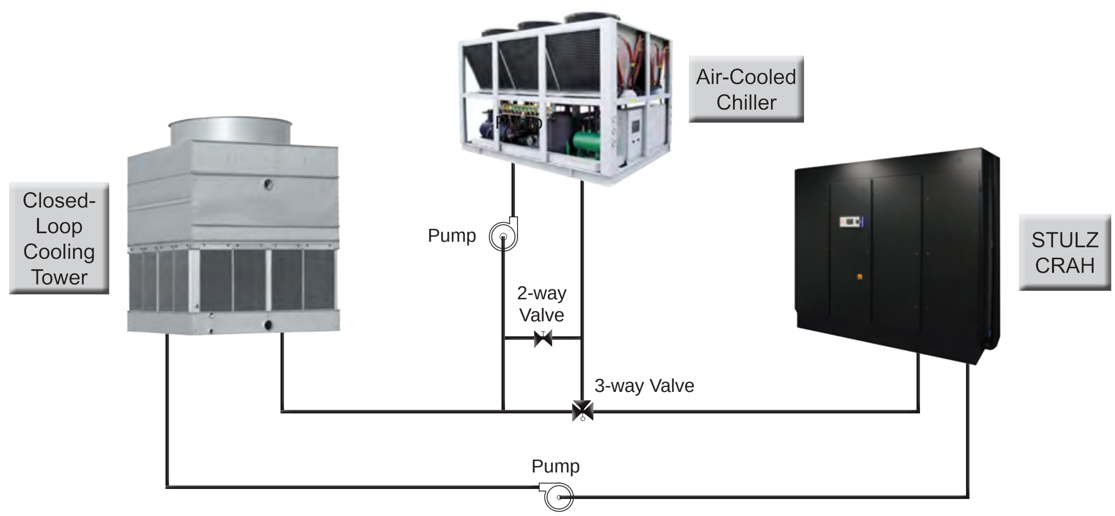
- Power Cost $0.10 per kWh
- Indoor conditions are 80/30%

Summary: Various CW-based economizer solutions display how different economizer systems compare with one another and how effective each solution is in different Climate Regions. A further analysis of return on investment (ROI) is provided in Appendix A. In the following pages we focus in on how the STULZ Dynamic Economizer Cooling Solution can be can be optimized significantly further by elevating the return air temperature and the supply water temperature.

STULZ Dynamic Economizer Cooling

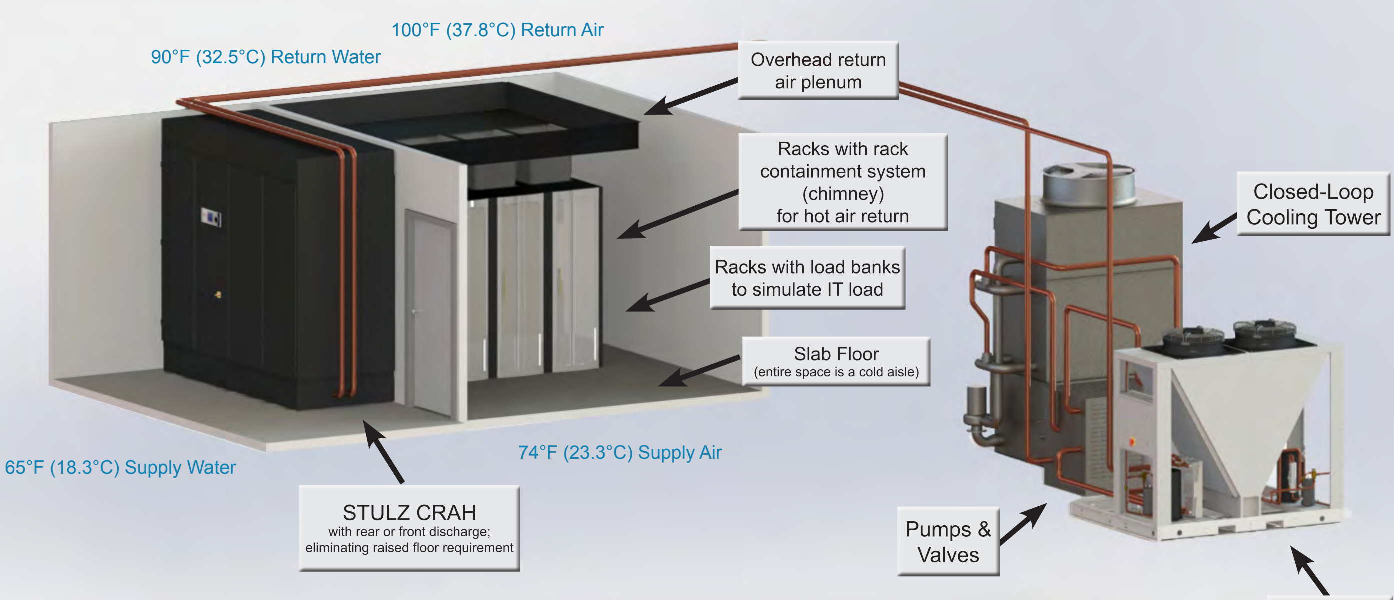
The STULZ Dynamic Economizer Cooling System utilizes a Chiller, Closed Loop Evaporative cooling tower, and variable speed pumps packaged with modulating valves to achieve incredible efficiency.
The STULZ (DEC) is not only an infrastructure but a design philosophy to optimize every piece of equipment in order to operate at the highest efficacy and lowest power usage through the entirety of the year. This is achieved using full containment and a warm water cooling strategy maximizing economizer and minimizing chiller assist hours, ensuring that chiller loading is kept to a minimum.

Mechanical System Schematic



The STULZ DEC Philosophy utilizes full containment to ensure that all heat is captured and returned to the CRAH unit. Capturing all of the server heat increases the return air temperature to the CRAH unit. This increased return air temperature allows the elevation of the supply water temperature. This warmer water temperature allows for increased economizer hours as the warmer fluid temperature is above the ambient temperature for more hours per year.

Reference Design - Dynamic Economizer Cooling with Optimized Operating Conditions



- 9°F (5°C) delta between Supply Water and Supply Air temp
- 26°F (14.5°C) delta between the Supply Air and Return Air temp
- 25°F (14.2°C) delta between the Supply Water and Return Water temp

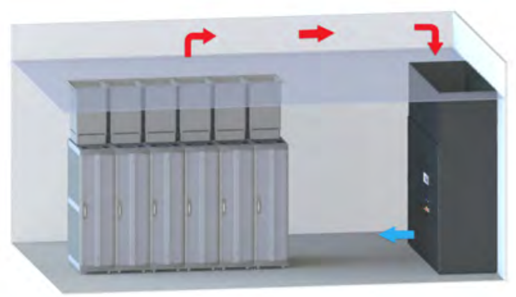
System Components

The STULZ Dynamic Economizer Cooling (Chiller Assisted Cooling) is an infrastructure and control system that involves multiple heat rejection devices. Each device operates at varying loads depending on the ambient dry bulb and wet bulb conditions. The system consists of the following primary components:

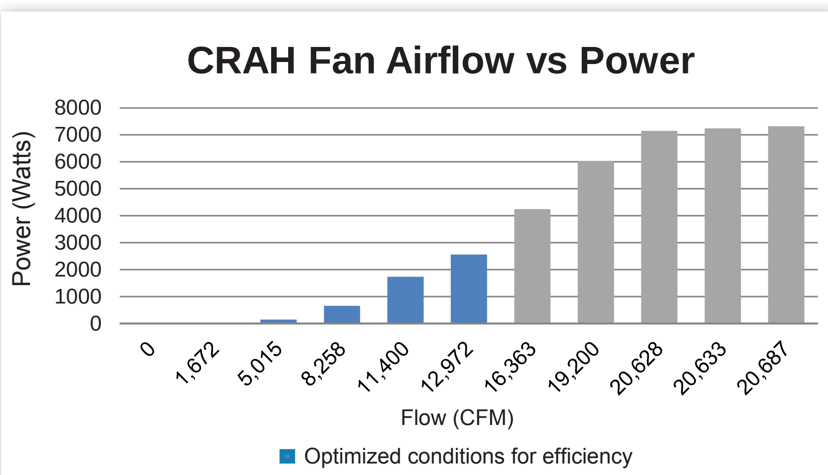
1 STULZ CRAH with Optimized Coil and Fan Speed Provides Highly Efficient "Warm Water" Cooling

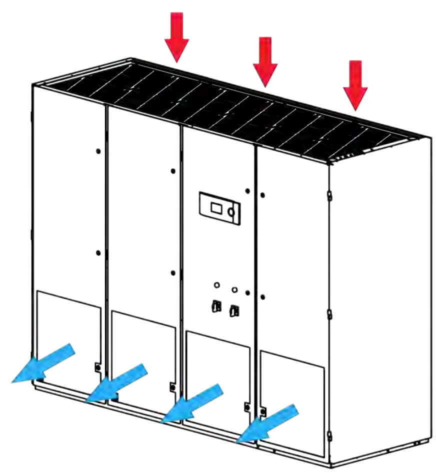
STULZ perimeter CRAH cooling units are ideal for "warm water" cooling. STULZ has designed chilled water coils with circuiting that enables a large water-side temperature difference. This contributes to significant increases in cooling tower and chiller efficiency, and thus energy savings. The coil is designed for the highest sensible heat ratio, while maintaining face velocities below 500 feet per minute. Lower fan speeds promote additional energy savings.

The fan location in the CRAH has been taken into careful consideration so that the EC fans provide the same highly efficient pressure and flow of air that you are used to with a STULZ CRAH with bottom discharge into a raised floor.



STULZ provides optional front discharge. This allows for the elimination of the raised floor, providing capital savings. In full containment infrastructure where server heat is ducted above the drop ceiling the entire room becomes the cold aisle.





Graph based on 1 unit; scalable to multiple units

2 Closed-Loop Cooling Tower
All-Year Primary Economizer Cooling

Dry Tower Mode:

In dry tower mode the ambient dry bulb temperature is well below the required cooling fluid temperature. In this mode, the leaving fluid from the CRAH unit is pumped through the closed loop cooling tower and back into the CRAH unit. The chiller and the chiller pump are not in use. This is referred to as dry mode because the needed heat rejection can be achieved without the sump on the cooling tower being used, thus the cooling tower can operate even when the ambient is below freezing.

Wet Tower Mode:

As the ambient temperature increases, the closed-loop cooling tower transitions from a dry operation to a wet operation. The wet operation of the closed loop cooling tower allows the tower to reject cooling fluid heat at a higher ambient temperature. This is achieved by an adiabatic cooling effect of small water droplets being pumped from the sump and spayed over the coil surface. The ability to reject the heat at a higher ambient temperature extends the amount of time you can operate without running the chiller and chiller pump, thus saving on compressorized cooling.

3 Air-Cooled Chiller used for Chiller Assisted Cooling

Sized to act as an assist device to provide additional (trim) capacity when the ambient conditions are unfavorable to run solely on cooling tower operation, or to maintain white space load should cooling tower fail.

Chiller Assist Mode:

The Chiller Assist Mode is used when the ambient or internal load has increased to a point that the cooling tower can no longer maintain the required water temperature. The 3-way valves change positions from bypassing the chiller to allowing a small amount of flow to go through the chiller. The chiller pump turns on and runs at a minimum initial speed. The Chiller powers up and the compressor begins, fully unloaded, and then slowly loads up to maintain the required leaving water temperature.

As the water temperature increases, the flow being diverted to the chiller by the chiller three-way valve increases, as does the speed of the chiller pump. When the flow increases to the chiller, the compressors continue to increase loading to maintain the fluid temperature. This increase continues until fluid temperature is at set point or the chillers compressor is fully loaded.

Compressorized operation uses significantly more power than just pumping a fluid or moving air with a fan. As such the cooling tower operation is always more efficient to operate than the compressors on the chiller.

The reason the chillers must be present is because when the ambient WB approaches the fluid temperature, the efficiency and heat rejection capacity of the water tower decreases, thus making it impossible to maintain the data center white space temperature without some form of direct expansion cooling.

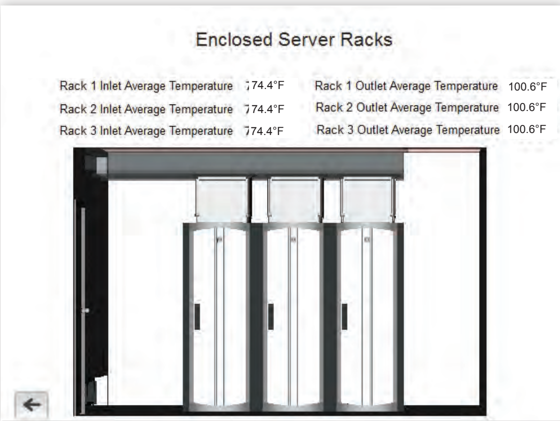
4 Pumps and Valves
Reduced Flow and High Delta-T

- Two variable speed pumps are used, one to provide flow to the cooling tower, and one to provide flow to the chiller.
- A three-way mixing valve is used to mix water from the cooling tower and chiller, or to bypass one device or the other.

Monitoring and Controls

Controls are the key element of a chiller assist cooling system and provide the link between the individual components. In order to ensure redundancy and fail-safe operation, an ideal control system provides a control structure based on a supervisory approach with a "top-down" configuration. The control system would need its own hardware platform with a link to the individual component controllers via a BMS protocol. In the event of a loss of communication, all component controllers would switch to a fail-safe mode and continue local operation at a pre-defined component-specific set point. All local set-points would be aligned with each other to allow uninterrupted operation. The system optimization is interrupted only until operation of the supervisory controller can be restored.

Example of Controls:

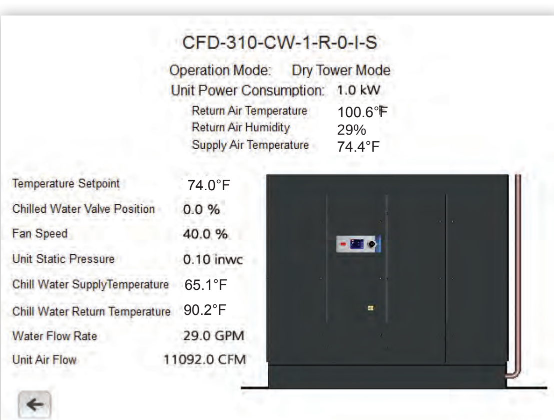


Racks (with load banks to simulate IT equipment)

1. Inlet Temperature: measures temperature into racks to ensure proper cooling of servers
2. Power Monitoring: measures power consumption of the racks IT equipment to determine what internal heat load is being generated

Outdoor Sensors

1. Ambient Temperature: measures the ambient Dry Bulb (DB) temperature to understand the effect on the outdoor equipment's mode of operation
2. Ambient Humidity: measures the Wet Bulb (WB) and the potential for using the wet mode of operation on the cooling tower
3. Barometric Pressure:
   - Determines the air density
   - Used as an input to both CRAH capacity calculations and CRAH airflow calculations



STULZ CRAH

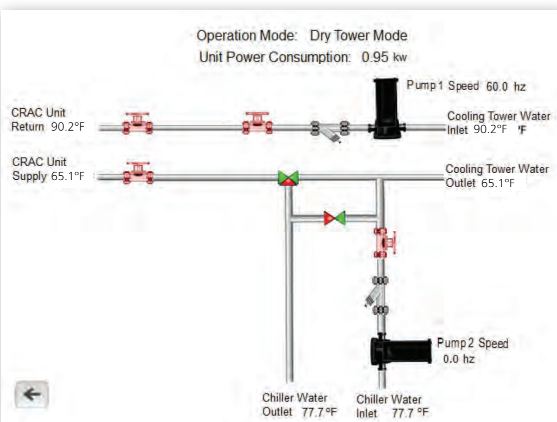
1. Return Temperature Sensor: measures the return air temperature from the room
2. Supply Temperature Sensor: measures temperature supplied from the CRAC
3. Fluid Flow Meter: used to verify the flow rate, to see the effects on efficiency, and to increase the flow prior to increasing the fan speed on the cooling tower.
4. Power Monitoring: measures power consumption of the unit to help determine efficiency in different operating modes.

Cooling Tower Pump

1. VFD Percentage: determines the speed of the pumps
2. Power Monitoring: measures power consumption of the pump to determine efficiency in different operating modes

Cooling Tower

1. Inlet Fluid Temperature: measures fluid temperature returning from the CRAH
2. Outlet Fluid Temperature: determines the delta-T across the tower at varying ambient conditions
3. Fan Speed: determines fan speed and the fan speed effect on tower operation at varying ambient conditions
4. Sump On/Off: monitors and determines the optimal effect of operating the tower as a wet tower
5. Power Monitoring: measures power consumption of the cooling tower to help determine efficiency in different operating modes



Chiller Pump and Valves

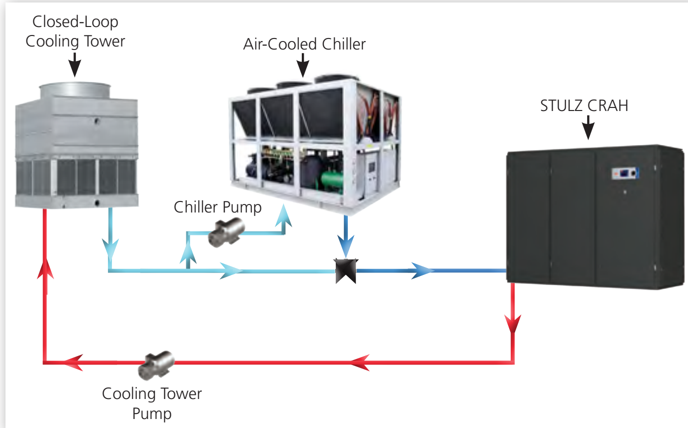
1. VFD Percentage: determines the speed of the pumps
2. Power Monitoring: measures power consumption of the pump to help determine efficiency in different operating modes
3. Temperature sensor determines position of mixing valve

Chiller (Assist)

1. Inlet Fluid Temperature: measures fluid temperature returning from the Cooling Tower or the CRAH unit, depending on the mode of operation
2. Outlet Fluid Temperature: determines the delta-T across the chiller at varying stages of loading

STULZ Dynamic Economizer Cooling

With the STULZ Dynamic Economizer Cooling system operating under optimized conditions, it becomes clear that the system provide state-of-the-art efficiency and contribute to some of the lowest PUE numbers found in the industry. A further discussion of ROI and PUE can be found in Appendix A.



30 ton CRAH: 100°F 20% RH Return Air, 65°F Entering Water /90°F Leaving Water

Baltimore, MD

	CRAH Coupled with Air Cooled Chiller				STULZ Dynamic Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Chiller	43.1	8760	100%	377,556	43.8	368	4.2%	16,116
Chiller Assist				-	26.02	4,139	47.2%	107,697
Wet Tower				-	8.60	765	8.7%	6,604
Dry Tower				-	6.18	3,488	39.8%	21,562
Yearly Total Unit Power Consumption (kWh)				**377,556**	-	-	-	**151,978**

Total kWh Savings Per Year: 225,578

Total Cost Savings Per Year: $22,558

Salt Lake City, UT (calculated at 4,500 ft altitude)

	CRAH Coupled with Air Cooled Chiller				STULZ Dynamic Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Chiller	44.0	8760	100%	385,440	45.65	555	6.3%	25,336
Chiller Assist				-	24.83	2,890	33.0%	71,773
Wet Tower				-	9.95	1,192	13.6%	11,858
Dry Tower				-	7.14	4,123	47.1%	29,446
Yearly Total Unit Power Consumption (kWh)				**385,440**		-	-	**138,413**

Total kWh Savings Per Year: 247,027

Total Cost Savings Per Year: $24,703

Portland, OR

	CRAH Coupled with Air Cooled Chiller				STULZ Dynamic Economizer Cooling			
Mode	kW	Hrs	% of Yr	Total kWh	Average kW	Hours	% of Year	Total kWh
Chiller	43.1	8760	100%	377,556	44.3	84	1.0%	3,720
Chiller Assist				-	18.0	4,560	52.1%	81,990
Wet Tower				-	8.7	599	6.8%	5,196
Dry Tower				-	6.5	3,517	40.1%	22,959
Yearly Total Unit Power Consumption (kWh)				**377,556**	-	-	-	**113,865**

Total kWh Savings Per Year: 263,691

Total Cost Savings Per Year: $26,369

- Pump is 65% efficient
- Chiller power is assumed as 1.23kW per ton
- Nominal 30 ton Chiller
- Nominal 30 ton Cooling Tower
- Based on 0% glycol
- kW average shown as actual kW varies over ambient range

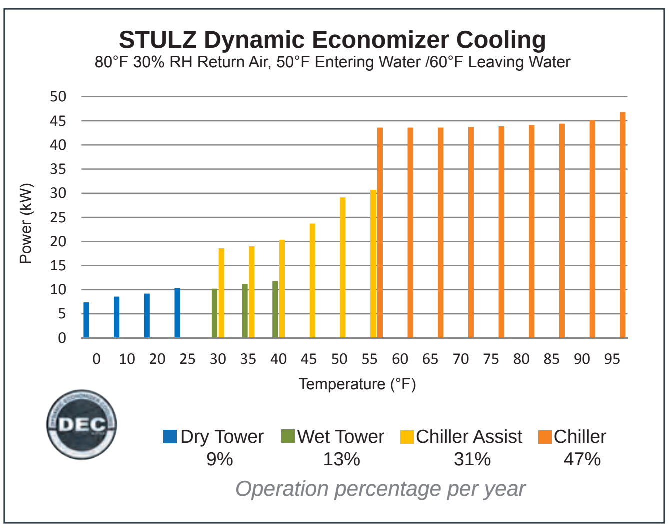
* 10¢ per kWh

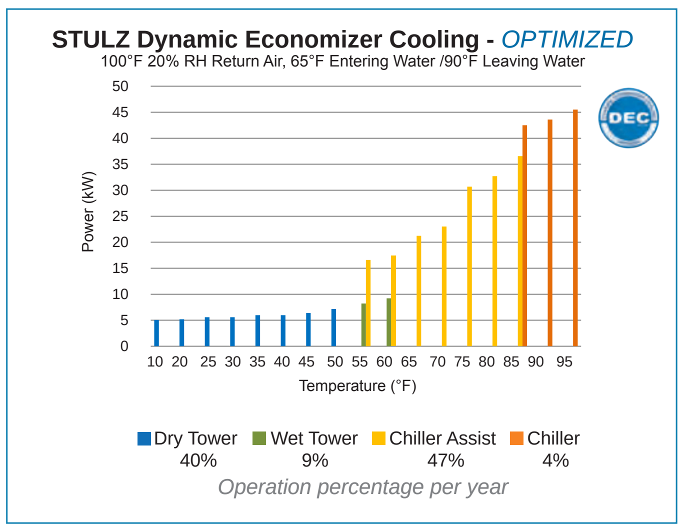
Comparison of Economizer Cooling

		CRAC DX			CRAH CW			
		80°F 30% RH Return Air			80°F 30% RH Return Air, 50°F Entering Water /60°F Leaving Water		100°F 20% RH Return Air, 65°F Entering/90°F Leaving Water	
		Traditional	Variable	Evaporative Tower	Dual-Source	STULZ Dynamic Economizer Cooling	**STULZ Dynamic Economizer Cooling**	
Baltimore MD	kWh Per Yr	406,580	323,476	317,084	314,947	266,534	**151,978**	**57%** Savings
	Operational Cost Per Yr	$40,658	$32,348	$31,708	$31,495	$26,653	**$15,197**	
Salt Lake City UT	kWh Per Yr	399,674	322,258	306,599	299,138	251,607	**138,413**	**55%** Savings
	Operational Cost Per Yr	$39,967	$32,226	$30,660	$29,914	$25,161	**$13,841**	
Portland OR	kWh Per Yr	414,583	332,012	356,393	355,024	266,640	**113,865**	**42%** Savings
	Operational Cost Per Yr	$41,458	$33,201	$35,639	$35,502	$26,664	**$11,386**	

• Power cost is $0.10 per kWh

Accumulation of Curves:





The chart illustrates the minimization of chiller operation by optimizing the conditions of the STULZ DEC Solution.

When selecting a water side economizer solution the optimal solution is dependent on several factors and preference including available infrastructure, climate region, redundancy requirements, ability to support/service different equipment and available capital versus operating budget.

Appendix A

Energy Measurement (PUE)

Power Usage Effectiveness or PUE was developed and recently clarified by Green Grid. PUE is a measurement for how efficiently a data center uses energy. It looks at how much energy is used by the computing equipment in contrast to cooling and power infrastructure and other overhead. In other words, PUE is a measure of the data center's effective use of power. It is the ratio of total amount of energy used by a computer data center facility to the energy delivered to computing equipment. PUE is dynamic and changes with outdoor temperature and humidity. Low PUE is the goal. The power used by mechanical cooling has represented a substantial portion of the overall data center power, however with the STULZ Dynamic Economizer Cooling System, PUE can be reduced significantly when deployed using optimized conditions.

PUE = Total Facility Energy / IT Equipment Energy. Greater than 2.0 is currently common. 1.6 is considered good. 1.2 or under is considered excellent.

STULZ economizer solutions help our customers achieve the lowest PUE's, and with the latest state-of-the-art economizer designs, customers can achieve PUE 's less than 1.2.

Return on Investment

Each of the water-side economizers detailed in this paper provide significant energy savings, but it is also necessary to look carefully at an overall return on investment (ROI) to determine which is right for you. Following is a table to help illustrate the potential ROI with each system based on weather conditions in Baltimore, MD:

Comparison - 1 MW System - Baltimore, MD
80°F / 30RH Comparison - 1 MW System - Baltimore, MD
80°F / 30RH

	CRAC DX FC				CRAH CW			
	Baseline Model							
	CRAC with Glycol Cooled Condenser	Traditional	Variable	Evaporative Tower	CRAH with Air Cooled Chiller	Dual-Source	STULZ Dynamic Economizer	**STULZ Dynamic Economizer**
CapEx Total	$ 358,300	$ 425,270	$ 544,471	$ 500,840	$621,680	$ 774,200	$ 757,780	**$ 733,180**
OpEx Annual	$ 438,153	$ 382,185	$ 304,071	$ 298,055	$ 354,897	$ 296,053	$ 250,538	**$ 142,852**
Additional Initial Investment	Base	$ 66,970	$ 186,171	$ 142,540	$ 263,380	$ 415,900	$ 399,480	**$ 374,880**
Yearly Energy Savings	Base	$ 55,968	$ 134,082	$ 140,098	$ 83,256	$ 142,100	$187,615	**$295,301**
ROI	Base	1.2 years	1.4 years	1.0 year	3.2 years	2.9 years	2.1 years	**1.3 years**
Opex Savings for 10 years	Base	$ 559,676	$ 1,340,816	$ 1,400,976	$ 832,558	$ 1,420,998	$ 1,876,146	**$2,953,010**

• System pricing includes major mechanical cooling system components only.
Does not include piping, electrical support systems, freight, or installation costs.

Additional Capital Savings (Cap-Ex)

Using the STULZ Dynamic Economizer Cooling System, there is opportunity for significant savings.

- The raised floor was eliminated by utilizing STULZ CRAH's with front discharge and racks with integrated hot air containment. The entire data center white space was used as a cold aisle.

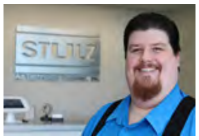
- The generator CapEx requirements and related maintenance was reduced, by specifying/sizing for the much lower energy required by the system.

Energy Rebates

STULZ water-side economizer solutions often qualify data center owners for significant energy rebates. Many utility companies are reaching high levels of capacity. They are offering incentives to companies that implement ways to save energy. With this guide, customers can demonstrate the tremendous energy savings that can be achieved. STULZ customers have received hundreds of thousands of dollars in rebates each year.

Author Bio:

Jason Derrick is a licensed professional engineer who has worked in multiple engineering disciplines. Jason has been employed as a senior applications engineer at STULZ Air Technology Systems since February of 2007. He is an expert in all aspects of precision air conditioning and data center cooling with a specialty concentration in ultrasonic humidification and water side economization. Prior to joining the STULZ team Jason worked as a consulting engineer in the petrochemical industry. Jason holds a Bachelors of Science degree in Mechanical Engineering from West Virginia University.



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STULZ Air Technology Systems, Inc.
1572 Tilco Drive, Frederick, Maryland 21704
Phone: 301.620.2033, Fax: 301.662.5487
E-mail: info@stulz-ats.com
www.STULZ.com

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