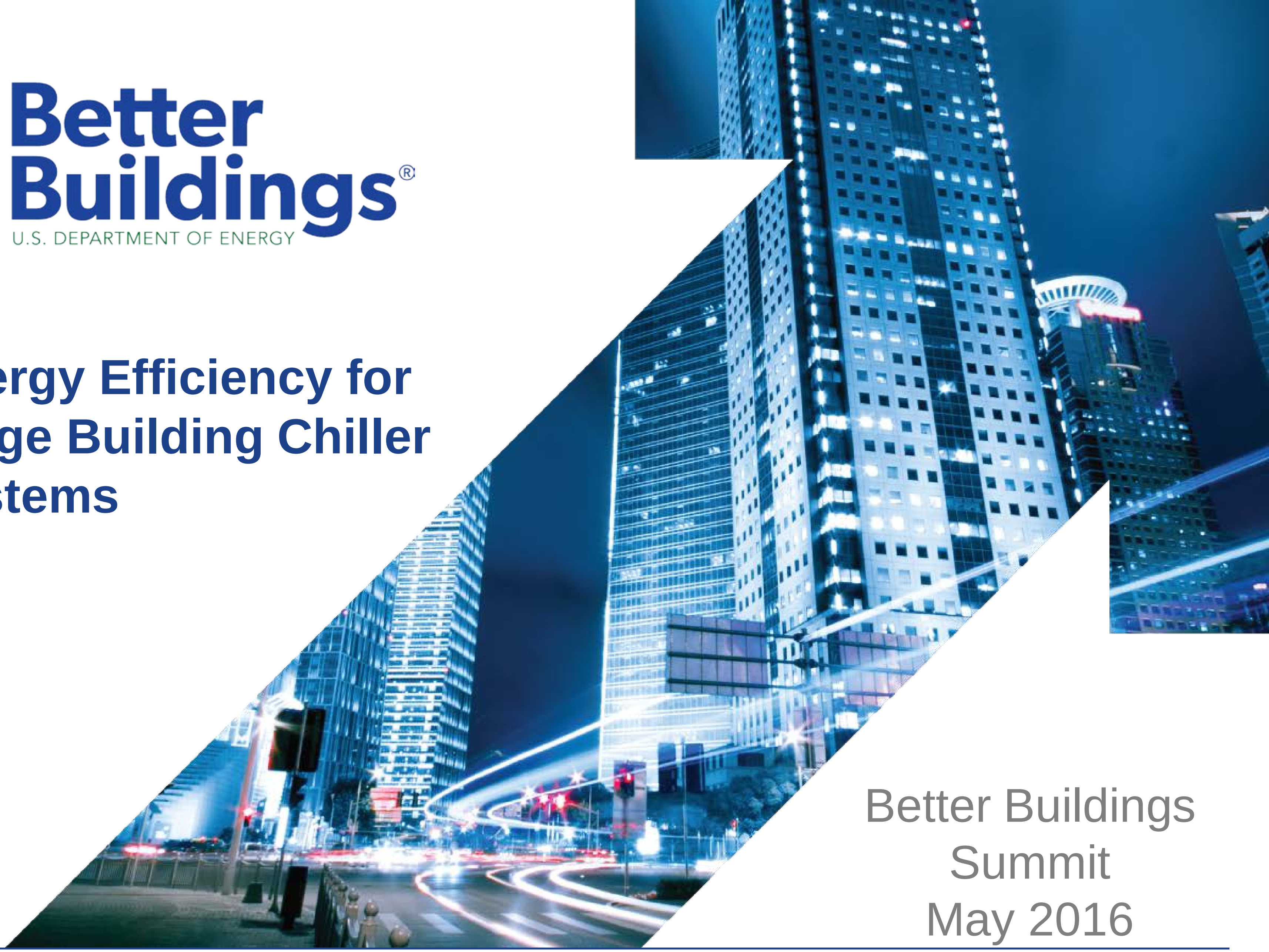
Energy Efficiency for Large Building Chiller Systems



Better Buildings Summit
May 2016

Introductions

Michael Deru
National Renewable Energy Laboratory

New resources

Matthew Gudorf
University of California Irvine

Large campus chiller efficiency opportunities

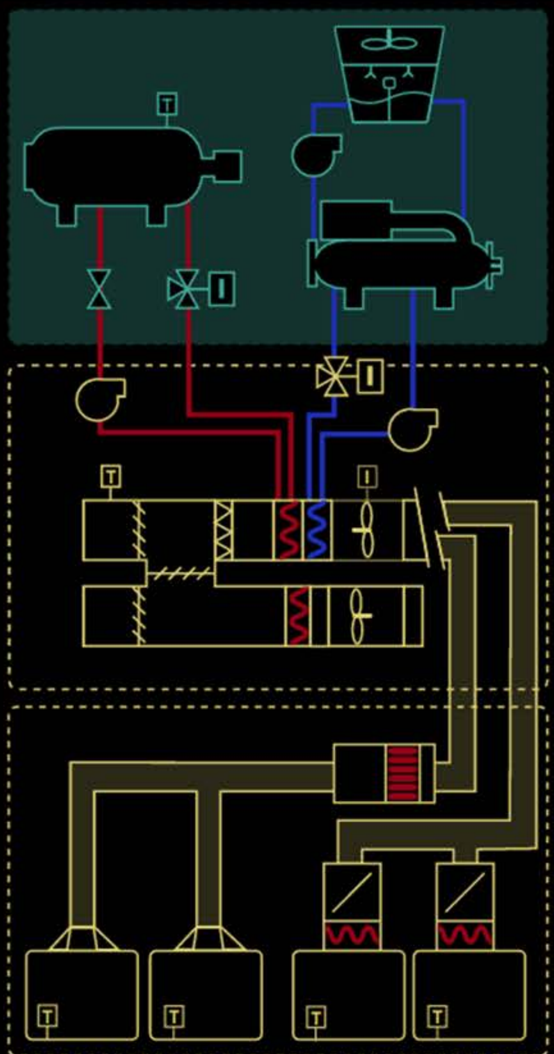
Glen Anderson
ETC Group

Deep dive into chiller performance

Central Plant Resource Map

HVAC Resources

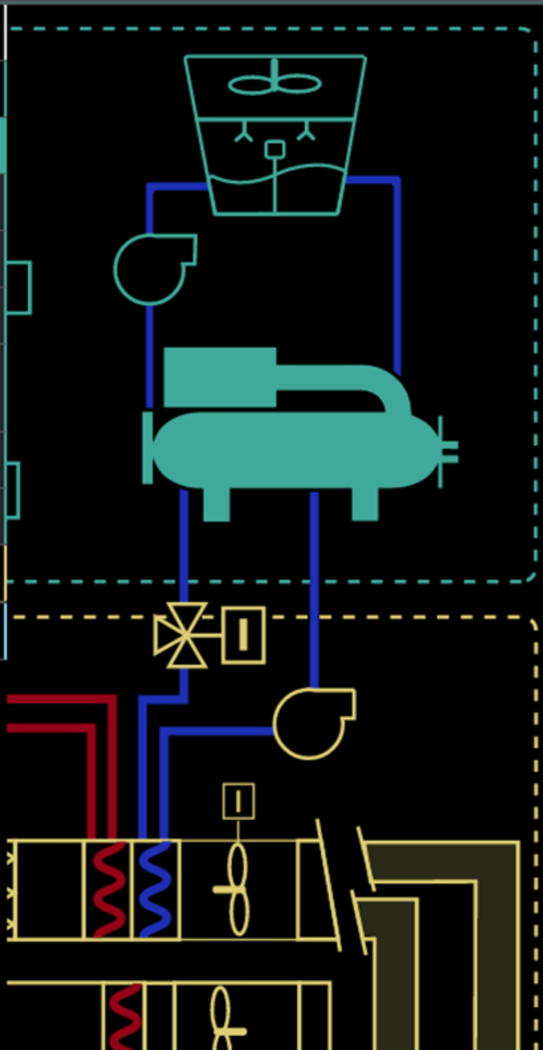
- HOME
- CENTRAL PLANT
- DISTRIBUTION SYSTEM
- SPACE LOADS



CENTRAL PLANT

Chilled Water Central Plants typically concise of chiller(s), chiller water pump(s), condenser water pump(s), cooling tower(s), water treatment system, controls, and energy metering. Typically chilled water central plants supply systems with cooling loads in excess of 50 tons that can range from one building to a campus of buildings. Use of cooling towers versus air cooled condensers found in smaller stand alone HVAC systems can save energy by using wet bulb temperatures versus drive bulb temperatures to reject heat from the cooling system. The added components in these systems adds to complexity of operations and a higher level of operator knowledge and control oversight than stand alone HVAC systems.

Central Plant Resource Map



HVAC Resources

- HOME
- CENTRAL PLANT
- Chiller
- Boiler
- Cooling Tower
- Pump
- Thermal Energy Storage
- Sensors & Controls
- Cogeneration Design
- DISTRIBUTION SYSTEM
- SPACE LOADS

Chiller

General Description and Uses

Chillers and air conditioners use one or more forms of energy to move thermal energy from one place to another thereby making one side colder and the other side hotter. Most chillers are based on using mechanical work with a working fluid (the refrigerant) to move thermal energy; however chillers can also be chemical, thermoelectric, thermoacoustic, or magnocaloric.

Vapor compression based chillers or refrigeration systems are based on moving a working fluid or refrigerant around a cycle comprised of four main components: compressor, condenser, expansion device, and evaporator. The compressor moves the refrigerant around the cycle and adds work (energy) to the vapor phase of the refrigerant by compressing it. The condenser rejects the heat from the hot vapor and condenses the refrigerant to a liquid. The expansion device allows a controlled expansion of the "hot" liquid refrigerant, which lowers its temperature and the evaporator is used to transfer heat from the area that is being cooled to the refrigerant.

Commonly Used Terms

IPLV (Integrated part-load value): A single-number figure of merit based on part-load EER, COP, or kW/ton expressing part-load efficiency for air-conditioning and heat pump equipment on the basis of weighted operation at specific increments of load capacities for the equipment. Typically used for ARI rating purposes. *Source: ASHRAE Terminology*

NPLV (Nonstandard part-load value): A single-number part-load efficiency figure of merit calculated and referenced to conditions other than IPLV conditions for units that are not designed to operate at ARI standard rating conditions. *Source: ASHRAE Terminology*

- General Info
- Types
- Codes & Standards
- Design Guides & EEMs
- Calculators & Tools
- Operation & Training
- Procurement & Performance
- Case Studies

How Well are Your Systems Performing?

End Use Energy Performance Targets

Inputs	
Building type	Large Office
Reporting units	kBtu/ft2/yr
Zip code	90210
County	Los Angeles
State	CA
Climate zone	3B-coast

In the "Inputs" box:
- Select the building type from the drop-down list.
- Select the desired reporting units in kBtu/ft²/yr, kWh/ft²/yr, MJ/m²/yr, or kWh/m²/yr.
- Enter the zip code.
- Verify that the county and state correspond to the building location.

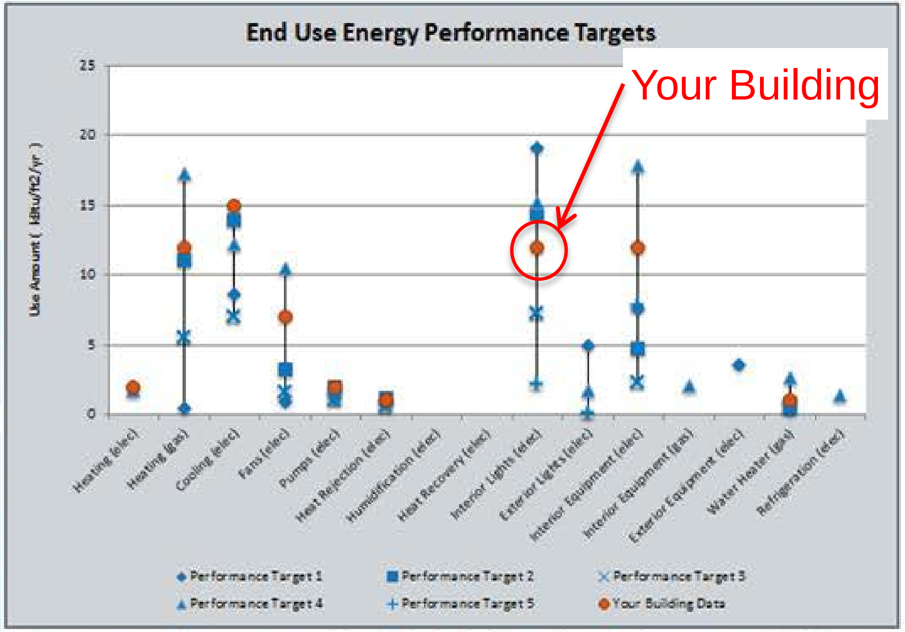
See the following tables for the specific information. Enter the building data in the white cells in the last column.

Data Details	Performance Target 1	Performance Target 2	Performance Target 3	Performance Target 4	Performance Target 5	Your Building
Data sources	DOE Reference Building	50% TSD Baseline	50% TSD Low Energy	CEUS	NREL Simulation	Acme Office
Data type	Simulation	Simulation	Simulation	Calibrated Simulation	As-Built Simulation	Sub-meter
Hours of operation (hours/week)	101.00	97.00	97.00	N/A	N/A	95.00

HVAC	Performance Target 1 kBtu/ft2/yr	Performance Target 2 kBtu/ft2/yr	Performance Target 3 kBtu/ft2/yr	Performance Target 4 kBtu/ft2/yr	Performance Target 5 kBtu/ft2/yr	Your Building kBtu/ft2/yr
Heating (elec)	0.00	0.00	0.00	1.67	ND	2.00
Heating (gas)	0.47	11.00	5.50	17.22	ND	12.00
Cooling (elec)	8.59	13.90	7.00	12.18	ND	15.00
Fans (elec)	0.95	3.20	1.60	10.44	ND	7.00
Pumps (elec)	1.11	2.00	1.00	0.00	ND	2.00
Heat rejection (elec)	0.92	1.10	0.60	0.00	ND	1.00
Humidification (elec)	0.00	0.00	0.00	0.00	0.00	0.00
Heat recovery (elec)	0.00	0.00	0.00	0.00	ND	

Lighting	Performance Target 1 kBtu/ft2/yr	Performance Target 2 kBtu/ft2/yr	Performance Target 3 kBtu/ft2/yr	Performance Target 4 kBtu/ft2/yr	Performance Target 5 kBtu/ft2/yr	Your Building kBtu/ft2/yr
Interior lights (elec)	19.08	14.40	7.20	15.22	2.16	12.00
Exterior lights (elec)	4.95	0.00	0.00	1.67	0.12	0.00

Process Loads	Performance Target 1 kBtu/ft2/yr	Performance Target 2 kBtu/ft2/yr	Performance Target 3 kBtu/ft2/yr	Performance Target 4 kBtu/ft2/yr	Performance Target 5 kBtu/ft2/yr	Your Building kBtu/ft2/yr
Interior equipment (elec)	7.58	4.70	2.30	17.81	7.84	12.00
Interior equipment (gas)	0.00	0.00	0.00	2.10	0.00	0.00
Exterior equipment (elec)	3.58	0.00	0.00	0.00	0.00	0.00



The End Use Energy Performance Targets graph shows the bands of performance for each end use. The values at the higher bounds represent the baseline values; the lower value solutions represent buildings that have better practices in that specific end use.

Compare your building to a range of standard benchmarks

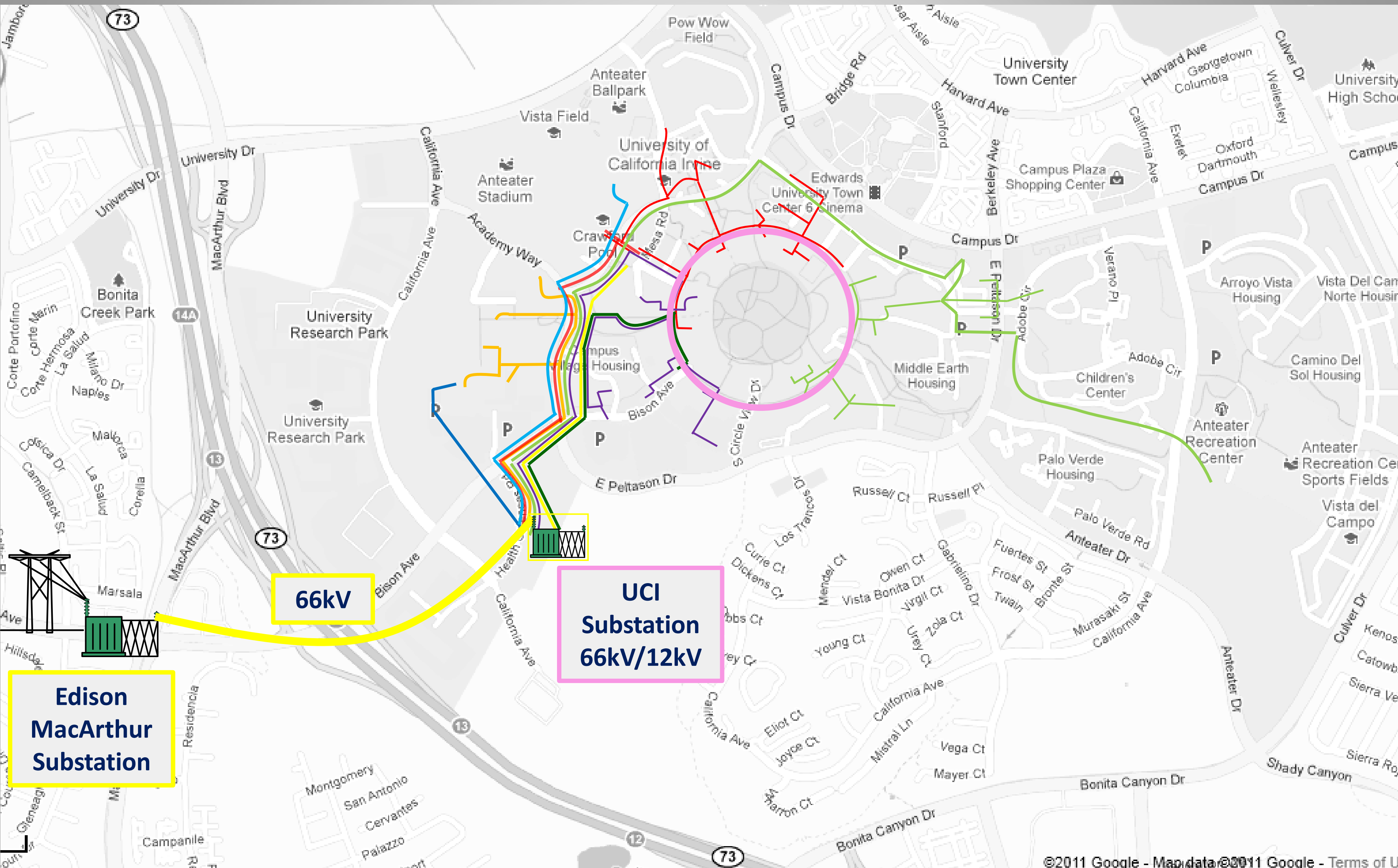
Matthew Gudorf
UC Irvine

U.S. DEPARTMENT OF ENERGY

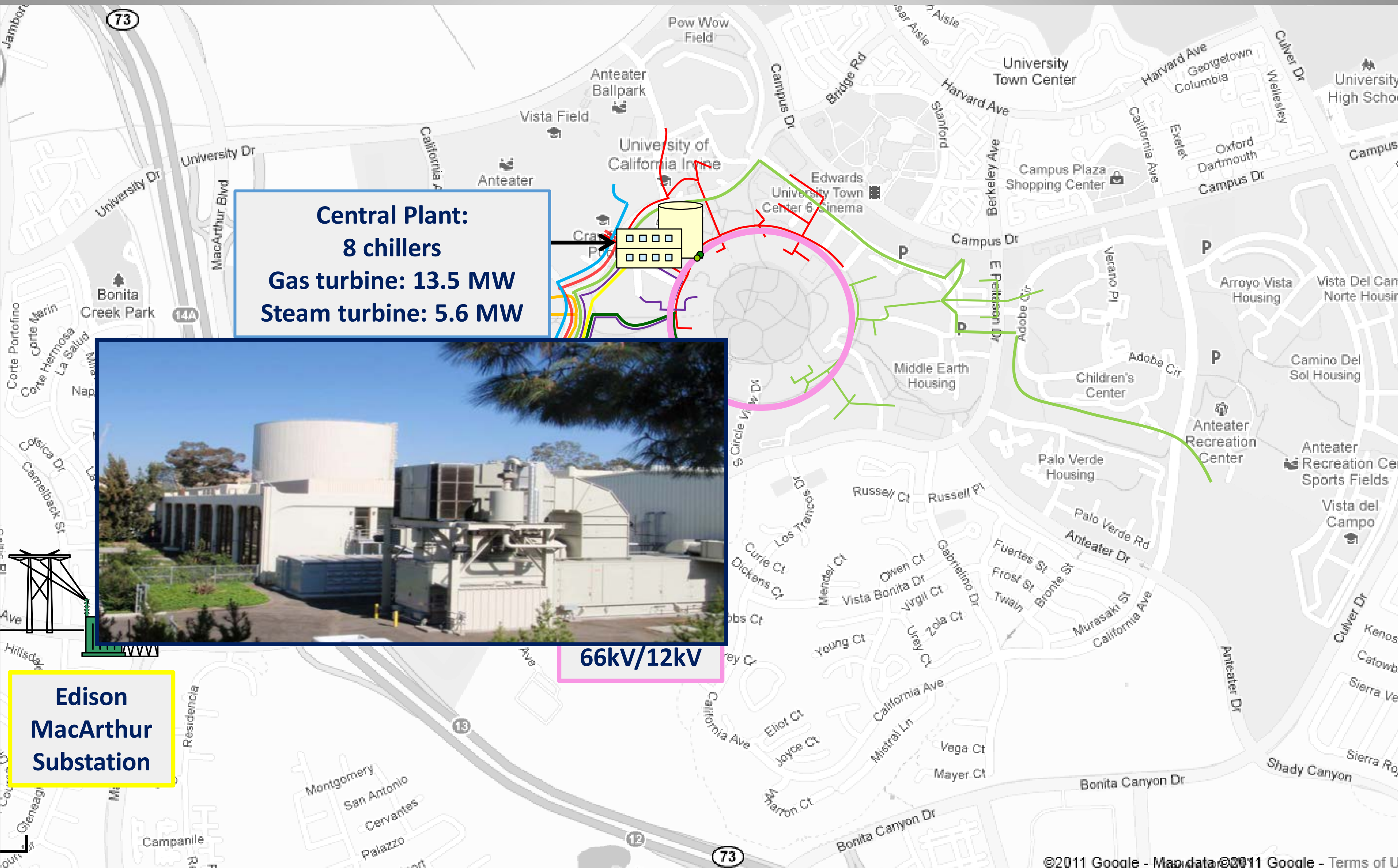
Quick Facts

- Established in 1965
- Comprehensive Research University
- 13 Lab buildings past two decades
- 8-24MW Load
- 1,526 Acres
- 10M+ Square feet
- 7.5M Sqft District Utilities
- 24,489 Undergraduates
- 6,268 Postgraduates
- $20,754,196 Utility Budget

Campus Utilities



Campus Utilities



Campus Utilities

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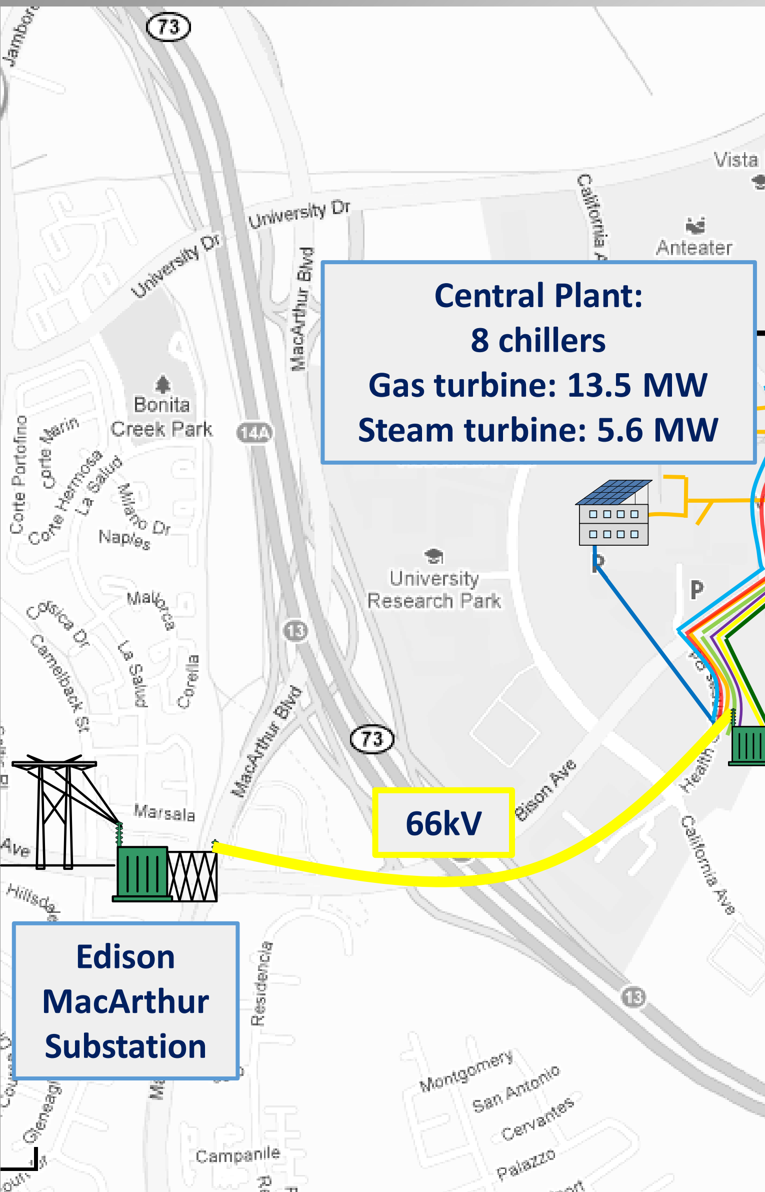
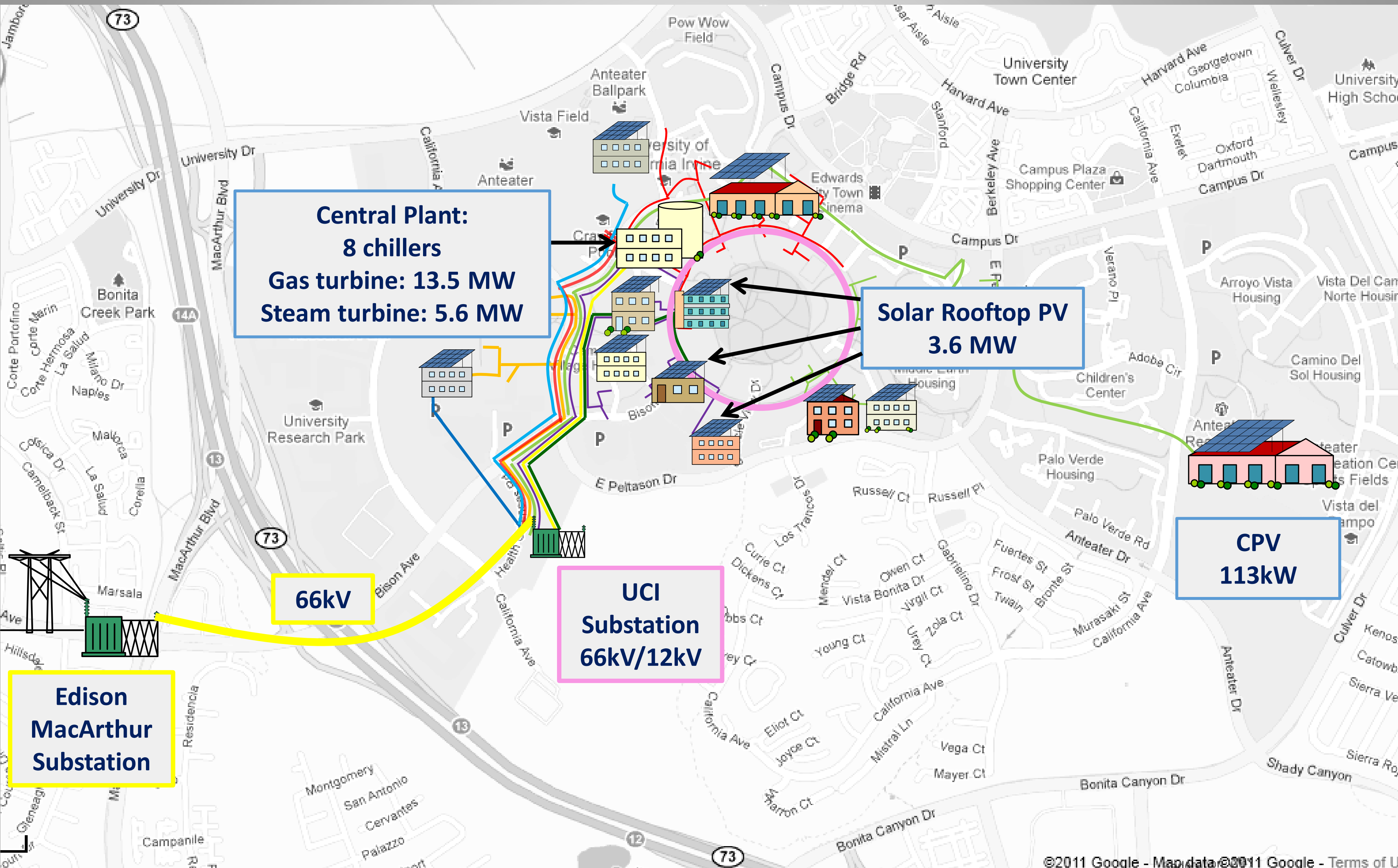
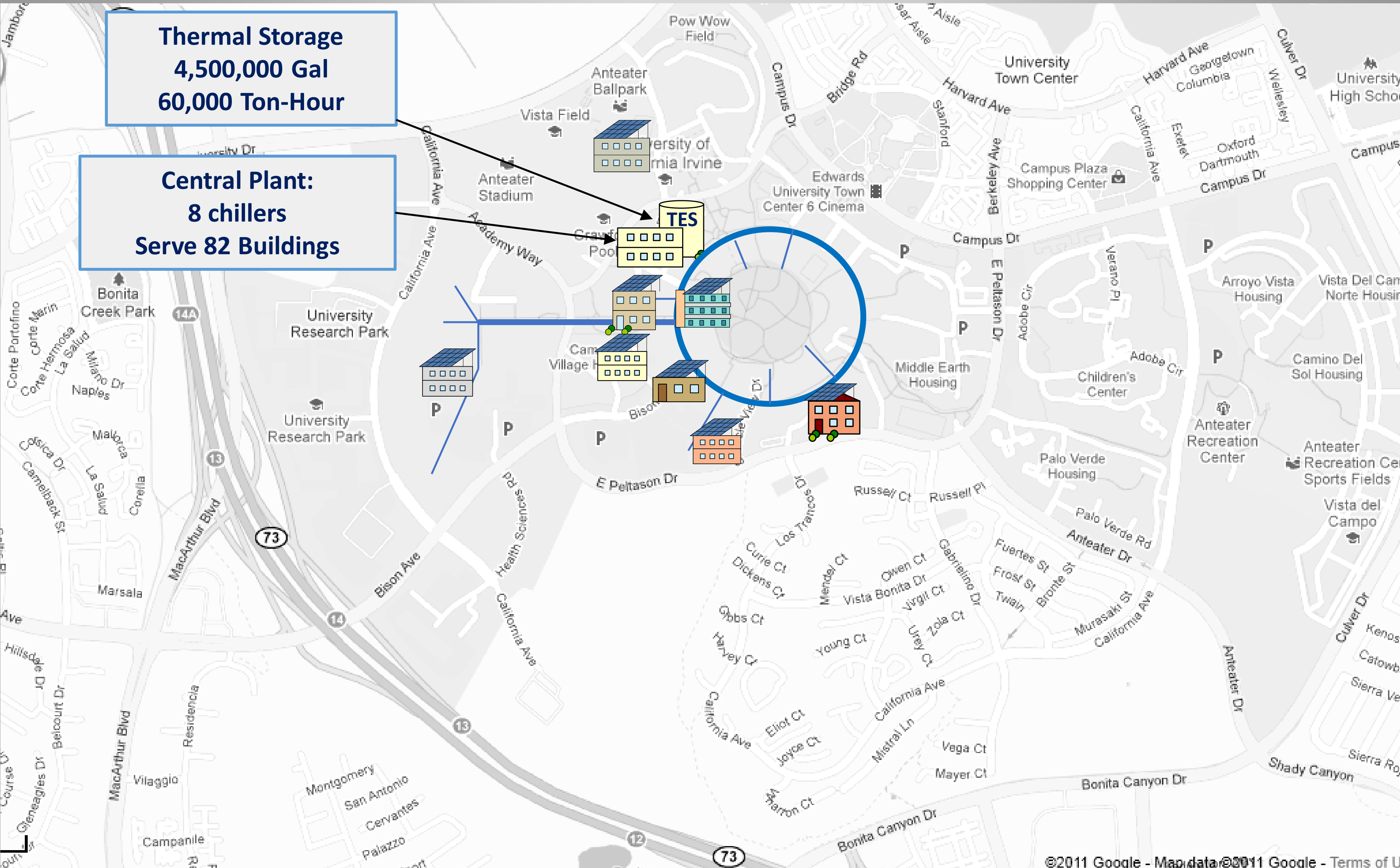


Campus Utilities



Campus Utilities



Chiller Plant Details

	Manufacture	Rating in Tons	Refrigerant	Year Installed
Chiller #1	Trane	1000	R-123	1992
Chiller #2	Trane	1000	R-123	1997
Chiller #3	Trane	1000	R-123	1997
Chiller #4	York	2000	R-134a	2002
Chiller #5	Trane	2500	R-123	1999
Chiller #6	Trane	2500	R-123	2004
Chiller #7	York	3000	R-134a	2007
Chiller #8	York	3000	R-134a	2007

16,000 Tons of nominal chiller capacity

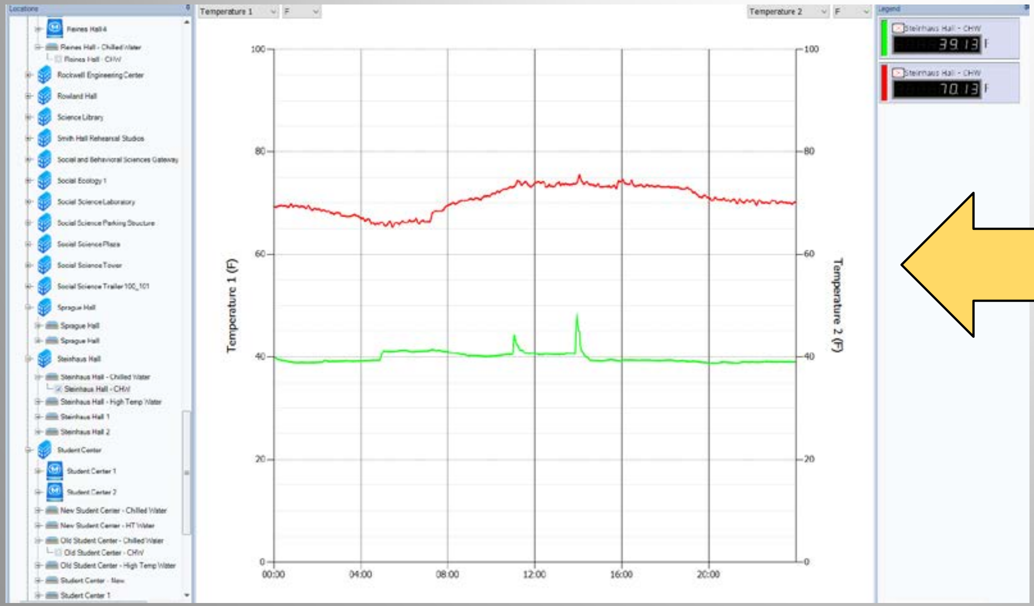
Chilled Water System

- AHU coils designed for 39°F supply
- System ΔT of 20-23°F
- PIC-V or Flow Limiters at each AHU
- Average load 3,100 tons
- Peak load 13,000 tons
- 74,400 Ton-Hours per day
- Flow Capacity @ 30" header is 35,600 gpm
- Secondary pump capacity 25,200 gpm @ 100 feet of head
- TES pump capacity is 22,700 gpm @ 90 feet of head
- Delivered 0.7kW per ton

Chilled Water Load Side Optimization

1997-2016 the campus changed out AHU coils to provide a ΔT minimum of 20°F at the same time stacked coils are re-piped reverse return to eliminate the need for balancing valves.

The system makes use of Pressure independent control valves and flow limiters to minimize use and maximize energy efficiency

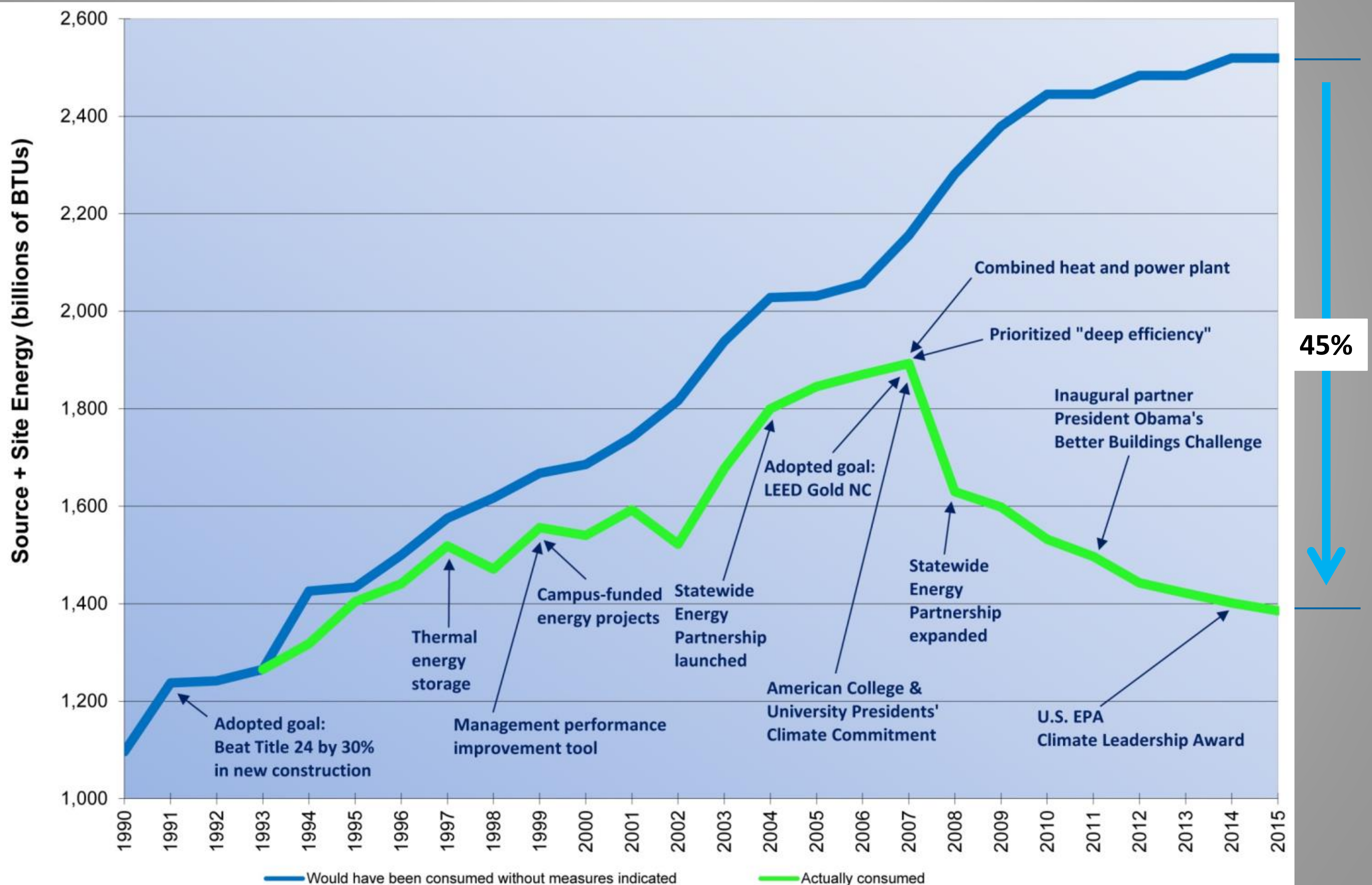


Monitoring the hydronic system at the building level

Thermal Energy Storage

- Tank holds 4.5 million gallons of chilled water
- Tank is 107’ tall by 88’ in diameter
- When chilled to 39°F, rated storage is 186,400 kWh
- 0-8MW of load can be shifted
- Originally built to shift load to off-peak rates

UC Irvine Drastically Reduces Load

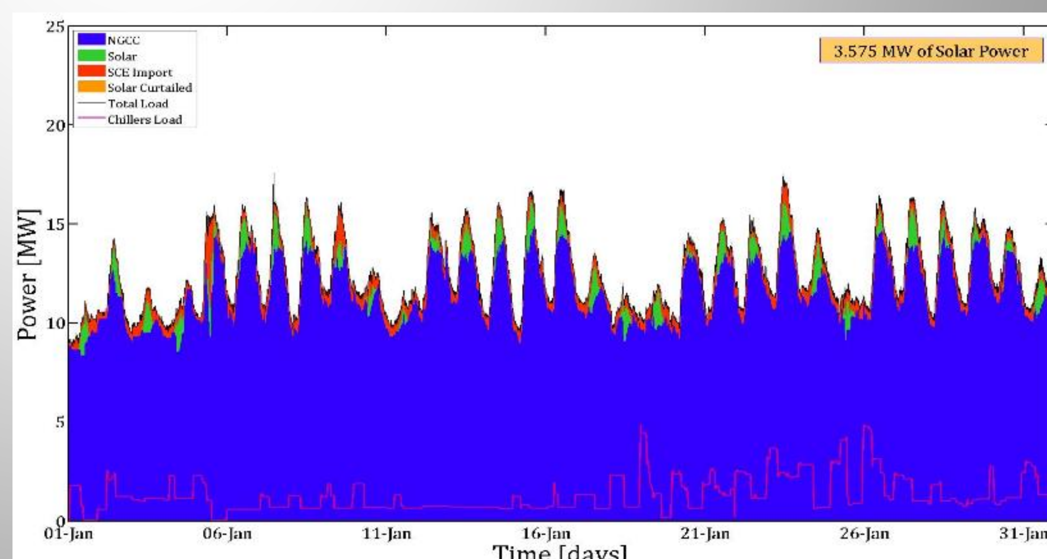


Operating Limitations

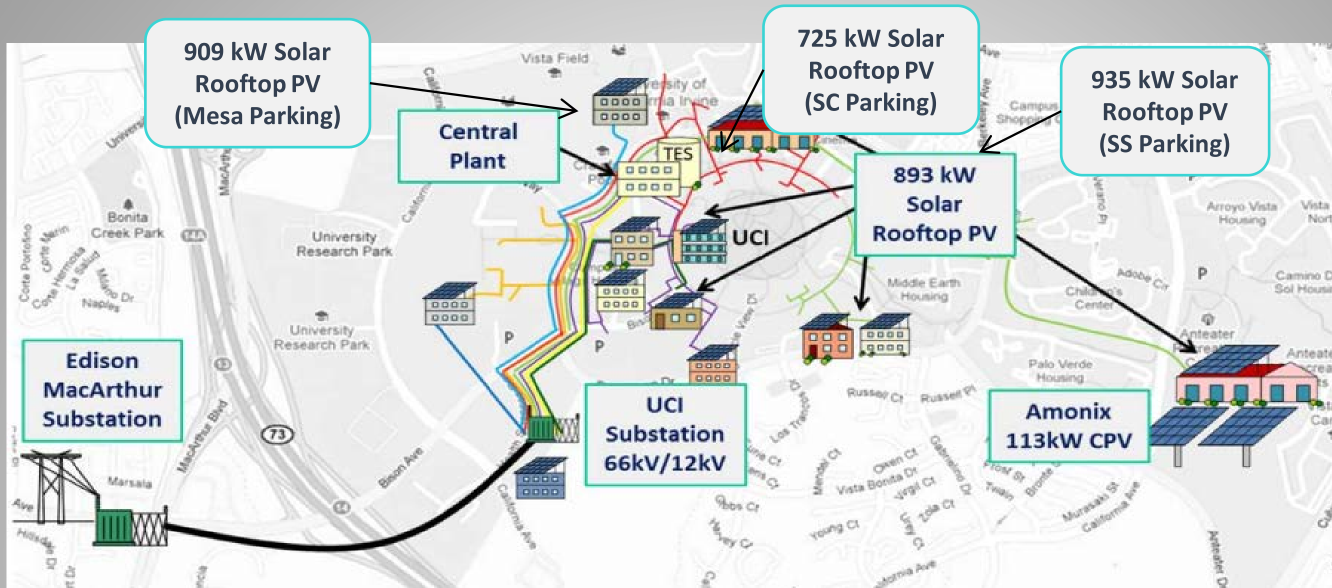
1	The interconnection agreement is for inadvertent export of power only.
2	Curtailment of the CTG is limited to 7.5MW due to emissions
3	Solar power production cannot be curtailed (PPA)
4	Efficiency of the CTG drops as output is reduced
5	Import electricity cost more than self generation

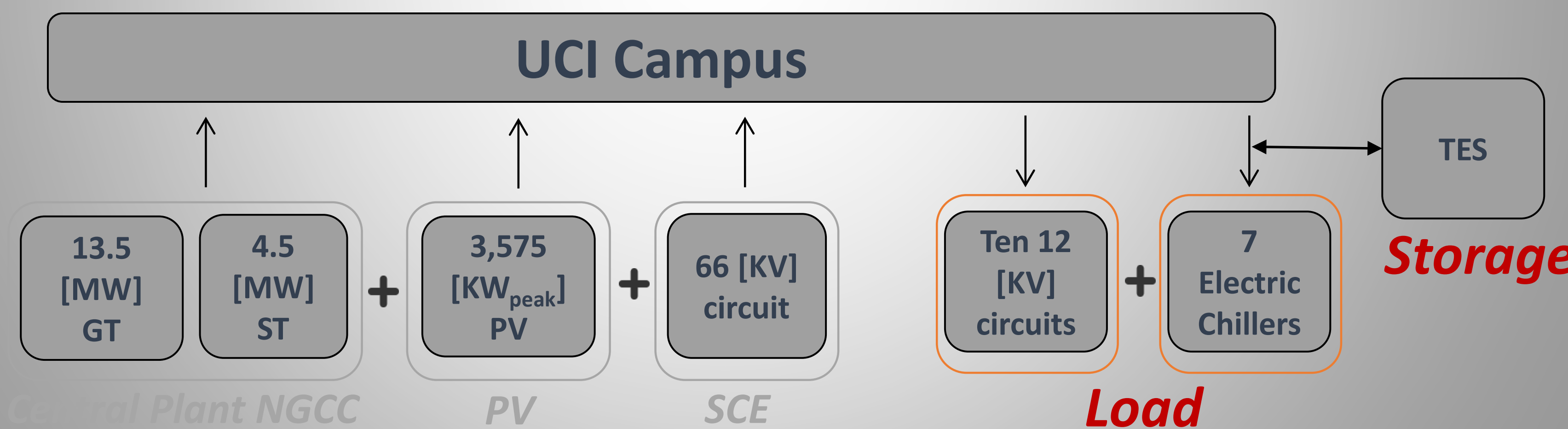
Load – **Generation** = **Import Electricity**

So how is the near perfect management as shown on the right achieved? UC Irvine uses TES as an electrical battery to flatten and shape load to match generation!



Balancing Load and Generation

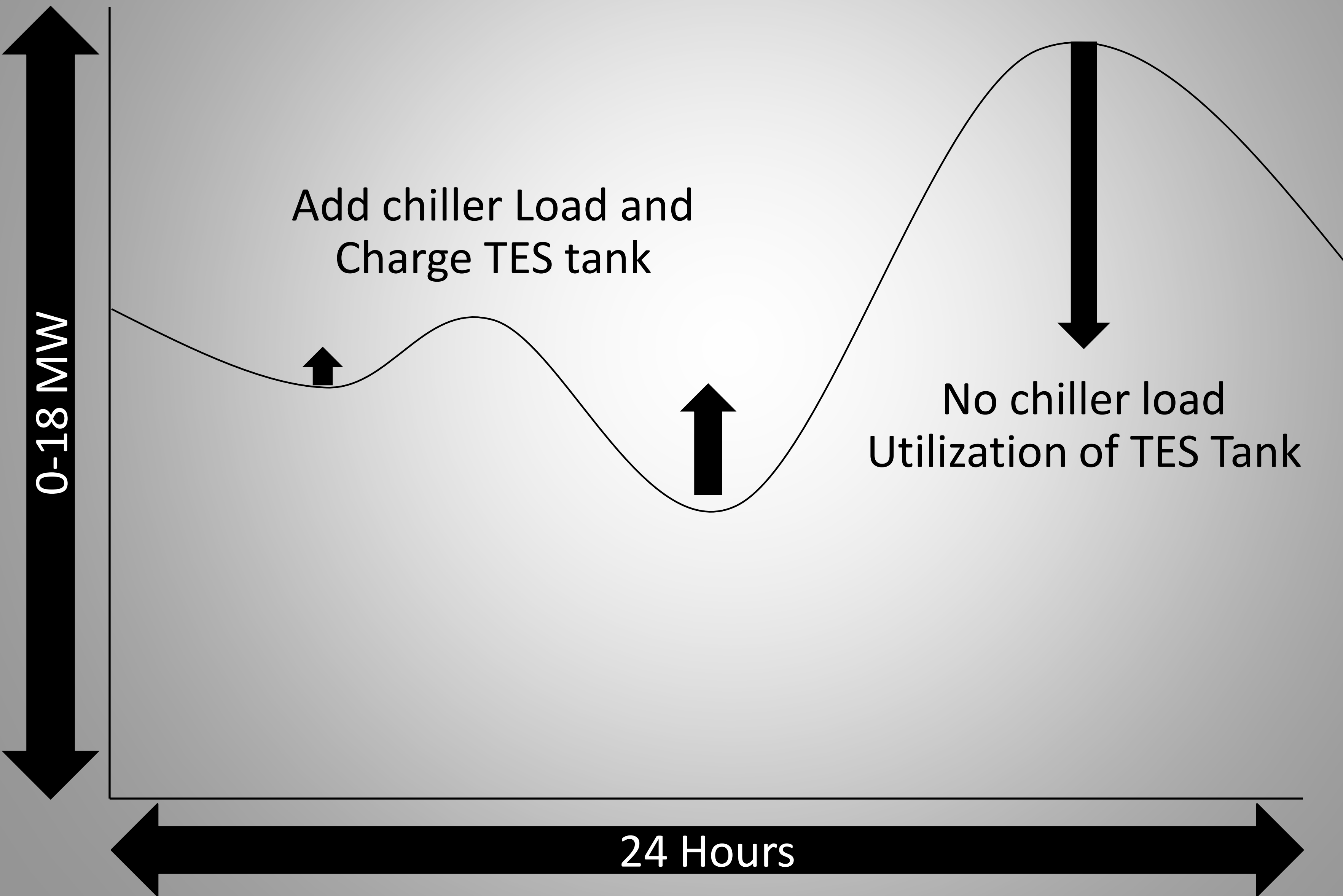




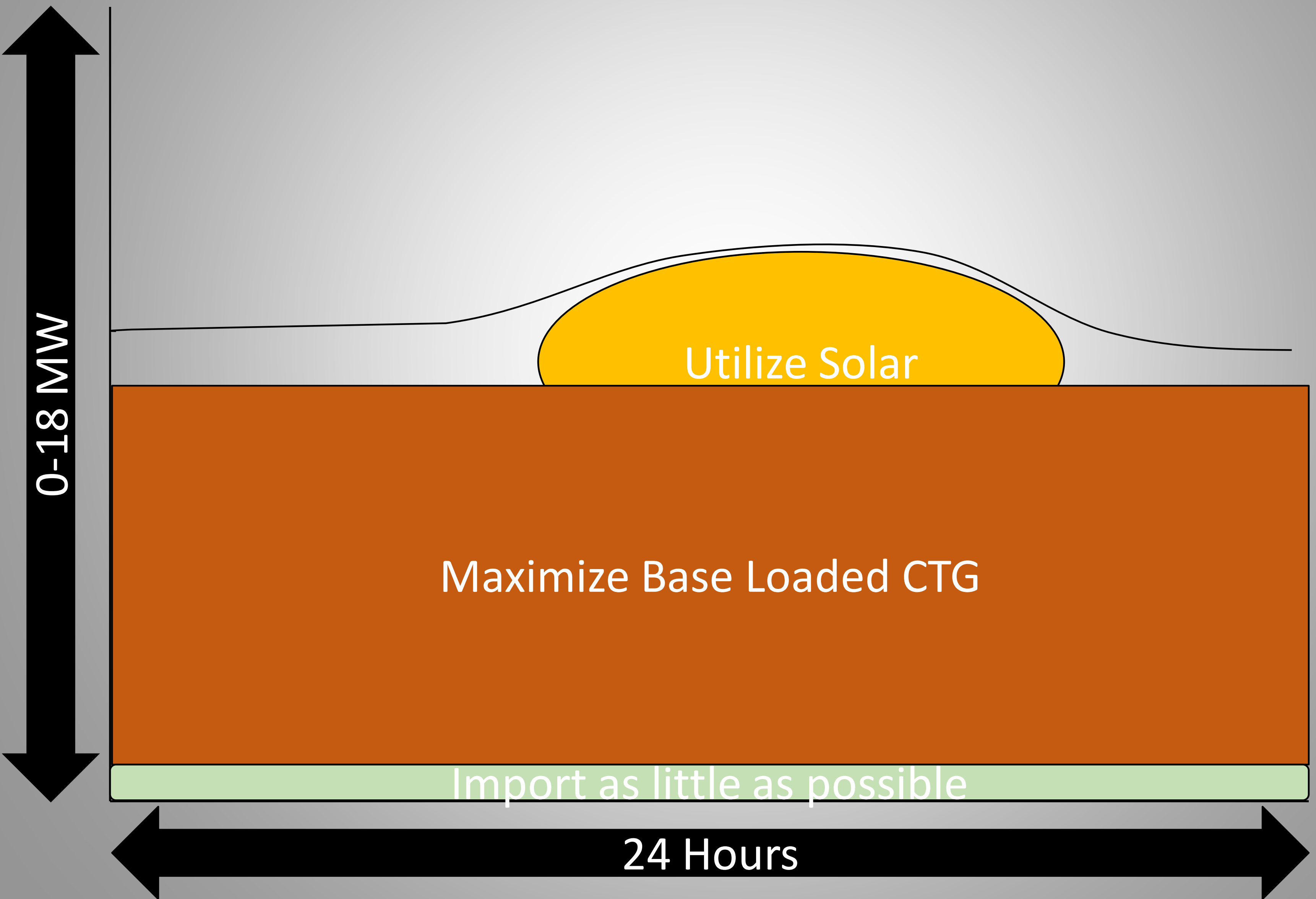
GT = Gas Turbine
ST = Steam Turbine

NGCC = Natural Gas Combined Cycle
SCE = Southern California Edison

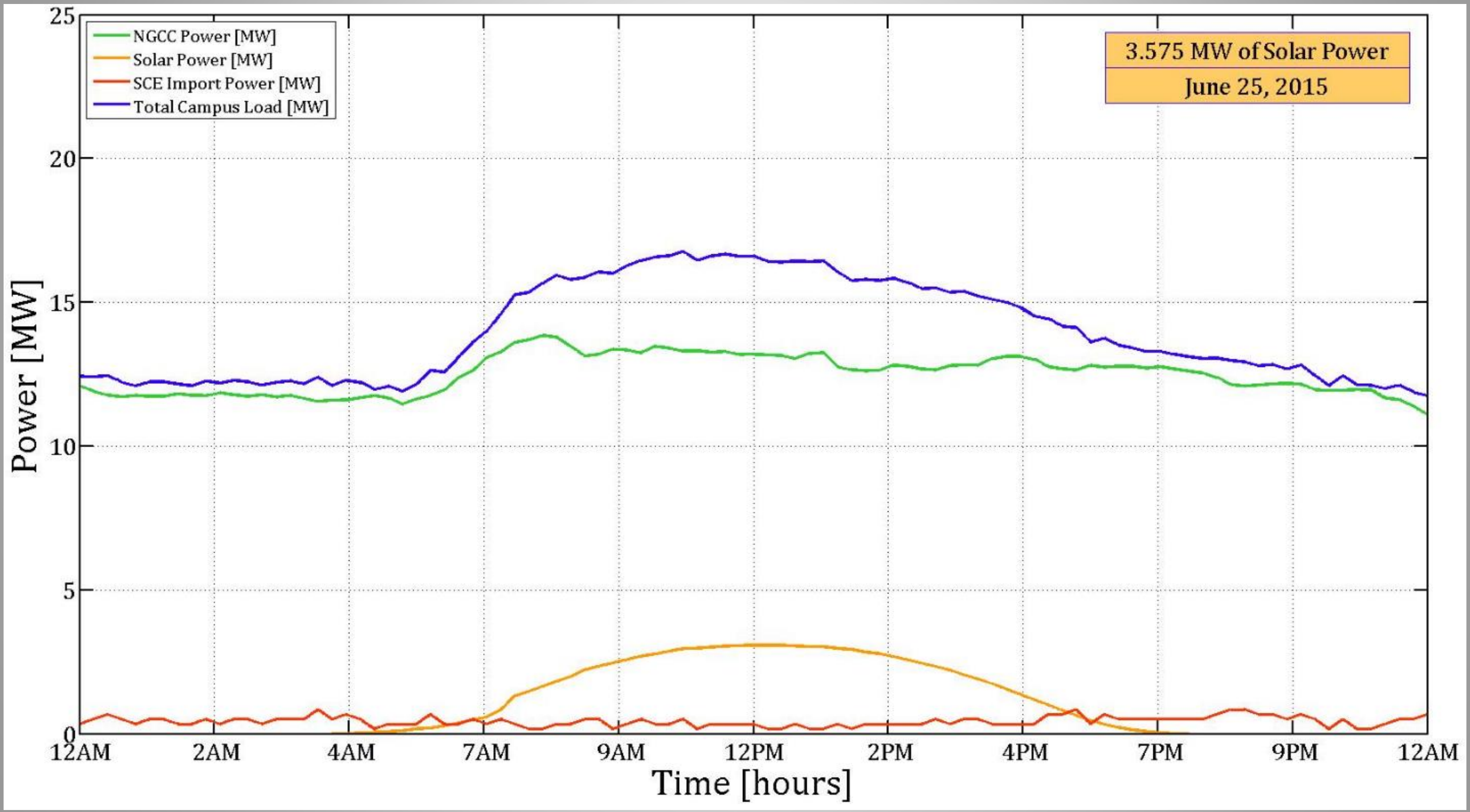
Duck curve with large swings
Does it all work?



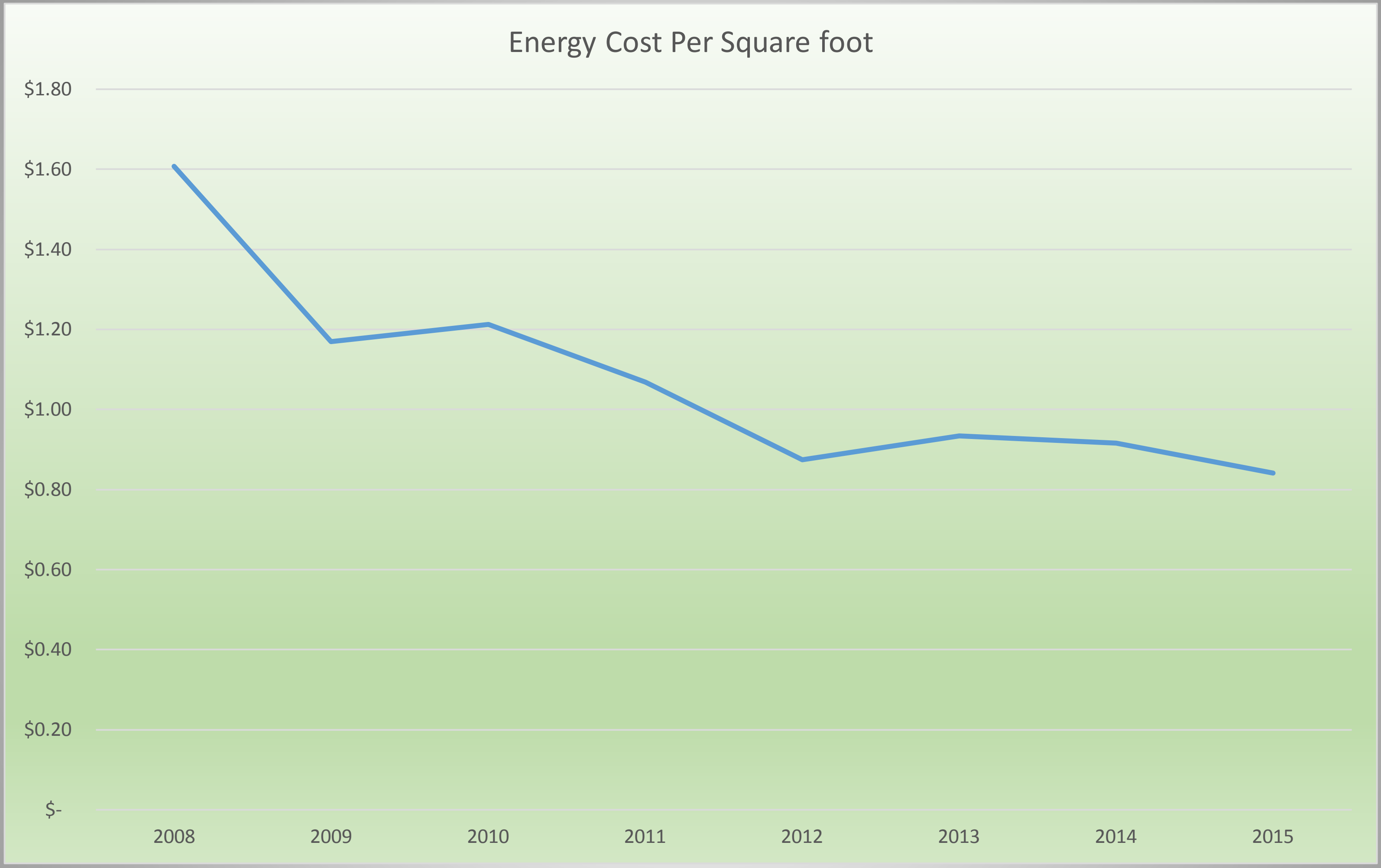
Flattest possible load shape Matched to Generation



Actual Load and Generation Graph From UCI Campus



Financial Savings



Optimization of load and generation results in financial savings

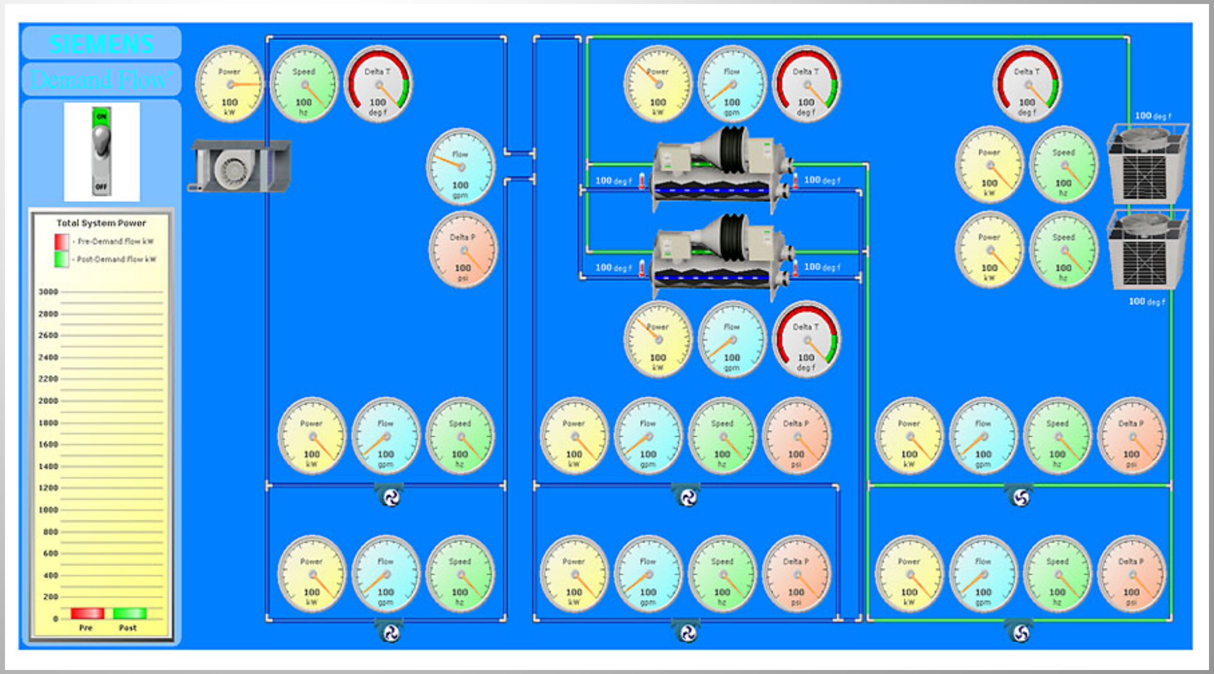
- Minimal import of expensive electricity
- Solar offsetting peak demand

Next steps

☑ Save energy and reduce load at each AHU
☑ Optimize electrical generation and load
☑ Optimize delta T of CHW system
☐ Optimize the chillers
- approach optimization (difference between the leaving water and the saturated refrigerant temperature
- lift optimization (difference between condenser refrigerant pressure and evaporator refrigerant pressure)
- cooling tower optimization pumps and fans

Plant staff shall select which chillers to run and when. The optimization system shall then optimize the selected equipment.

Load shape and maintaining load will takes precedence.



Glen Anderson
ETC Group

U.S. DEPARTMENT OF
ENERGY

OPENING THE BLACK BOX

2016 Better Buildings Summit
Washington DC
May 11, 2016

Glen R Anderson, PE

Outline

- What drives chiller efficiency?
- How can you check each component of a chiller?
- Case studies of completing live chiller performance testing


YORK

Tools to Open the Black Box

2 pressures from service ports

Electrical input

7 surface temperatures

COLLECTING AND ANALYZING DATA

Climacheck hardware

Portable for occasional measurements :

- For commissioning and service
- Connected to local PC or the Climacheck server

Fixed installations:

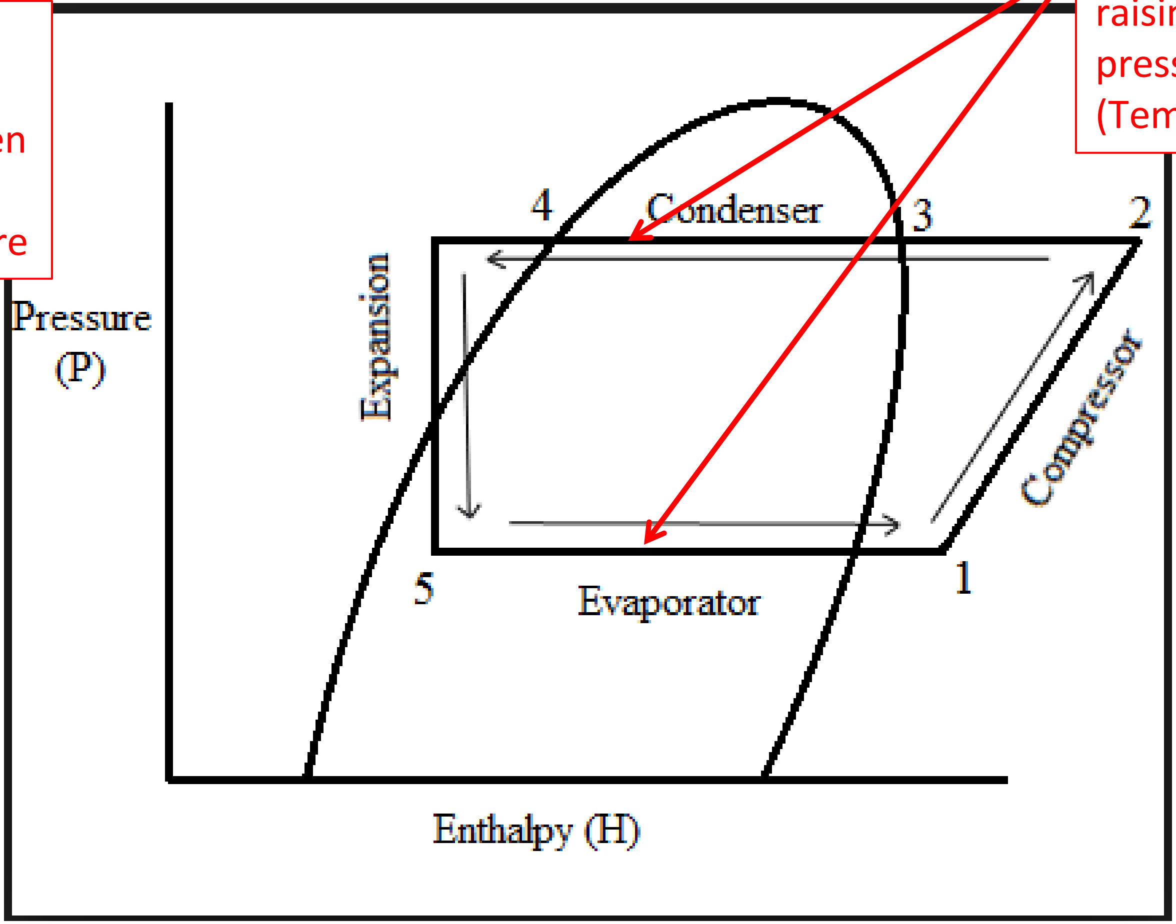
- Installed in systems for continues monitoring.
- Connected to local PC or the Climacheck server
- Energy statistics
- Early warnings


YORK
MAX
Centrifugal Chiller

REFRIGERATION CYCLE

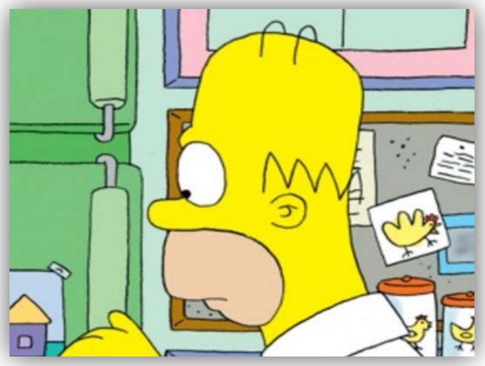
Work is proportional to difference between evaporator and condenser pressure

Reduce work by dropping **condenser** pressure (Temperature) or raising **evaporator** pressure (Temperature)

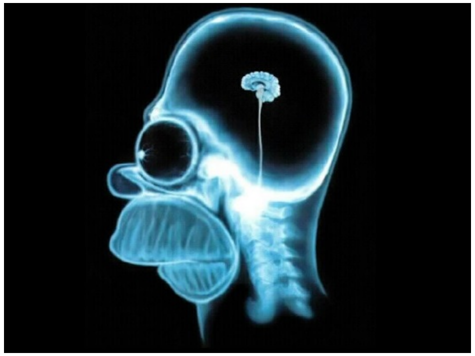


Opening the Black Box

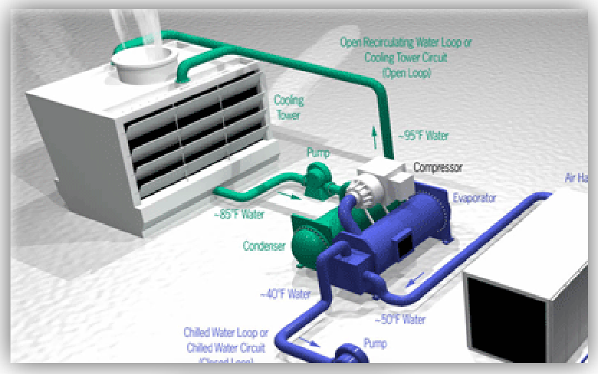
- Human Head



X-Rays



- Chiller



Opening the Black Box

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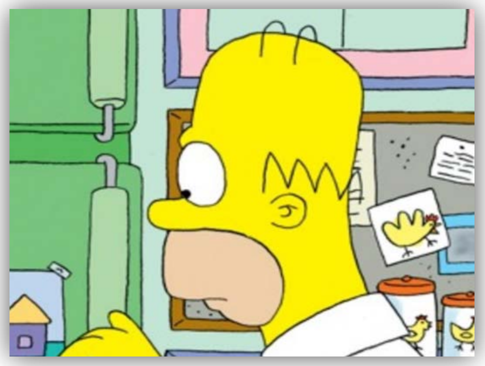

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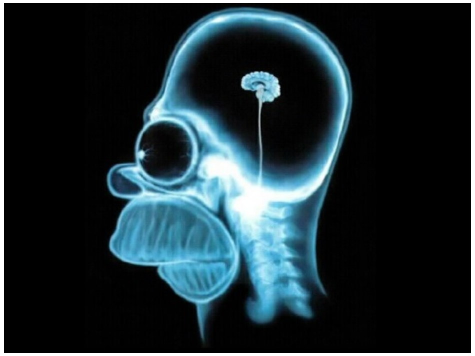
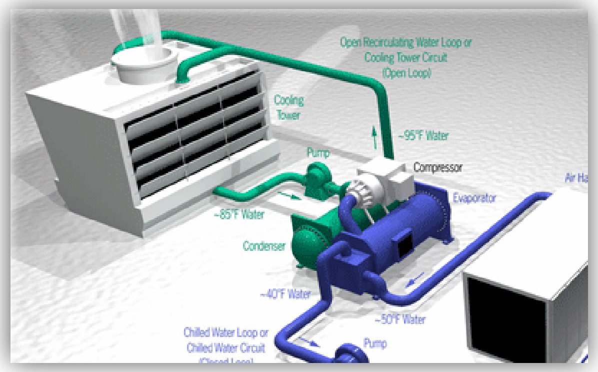
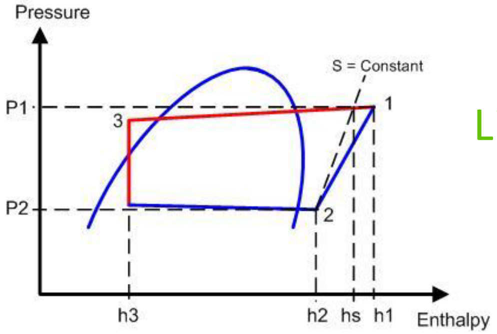


- Chiller

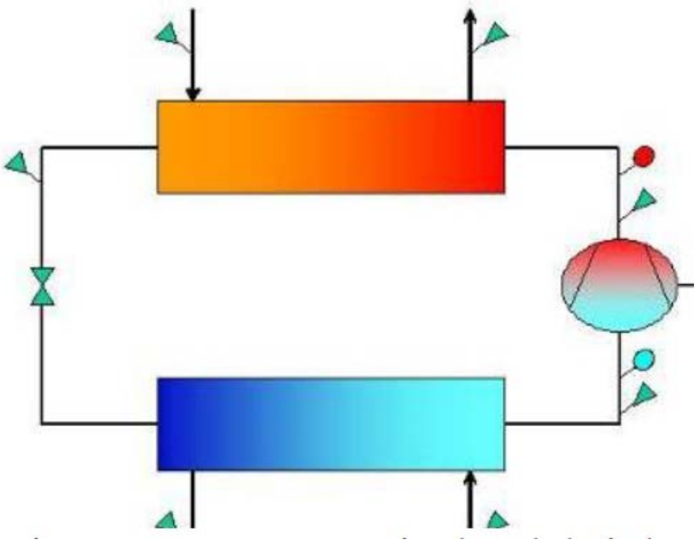


Live Chiller Performance Test

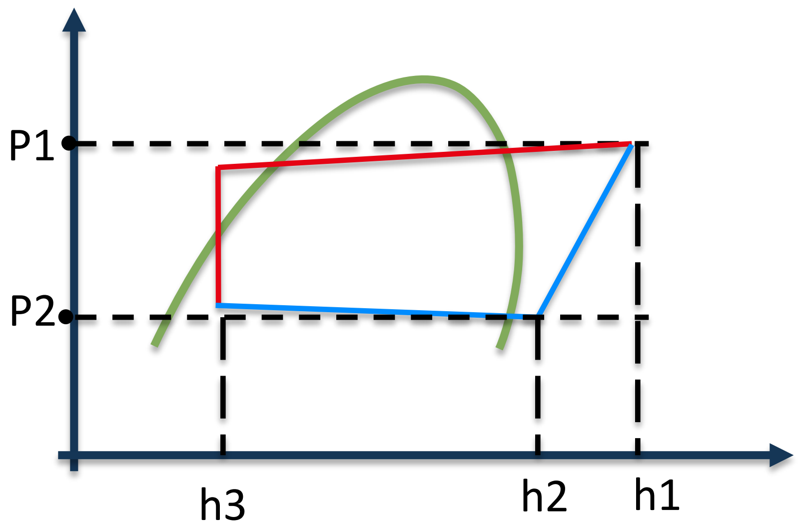


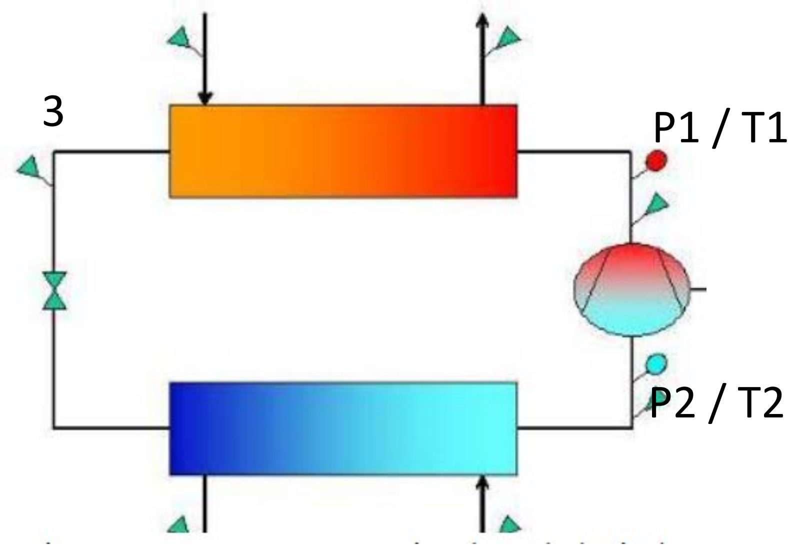
Live Actual COP

What the Chiller Performance Test Does



What the Chiller Performance Test Does

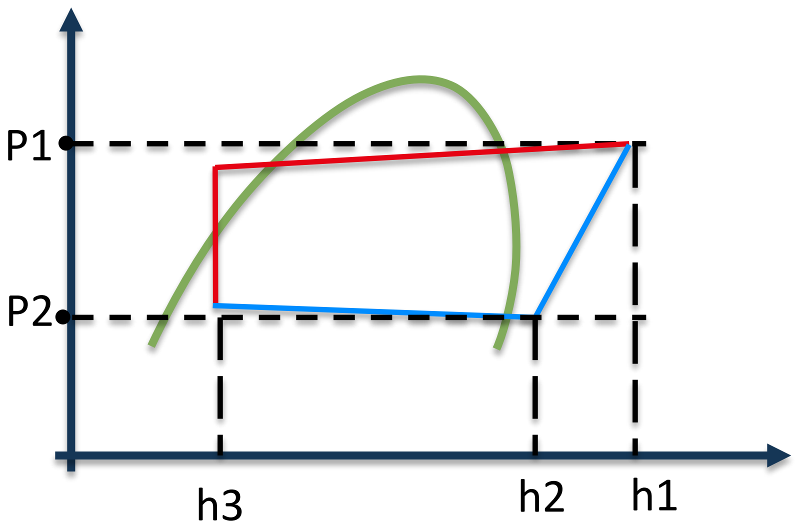


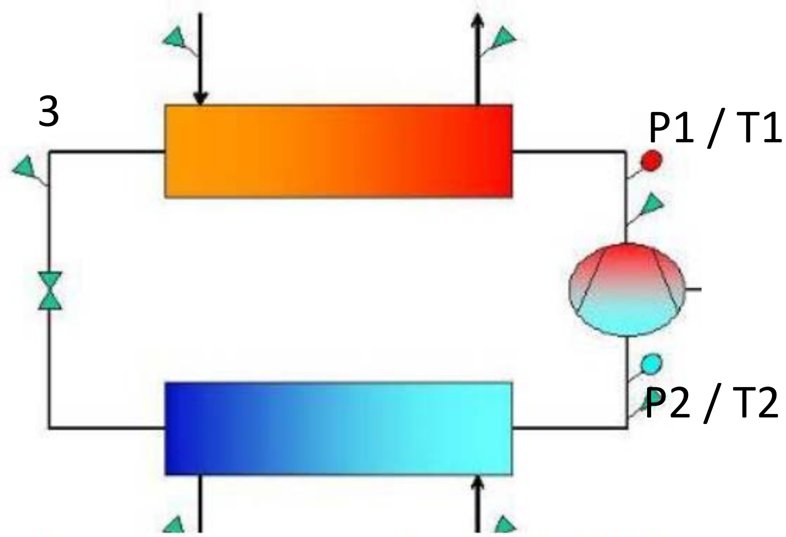


Cycle Cooling Capacity

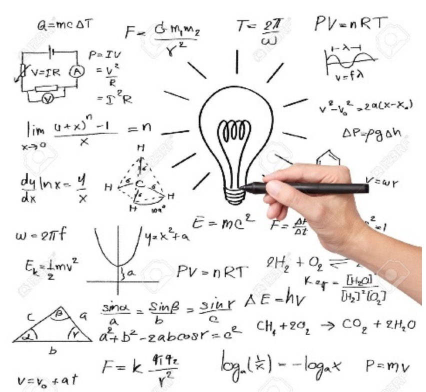
Cycle Compression Work

What the Chiller Performance Test Does

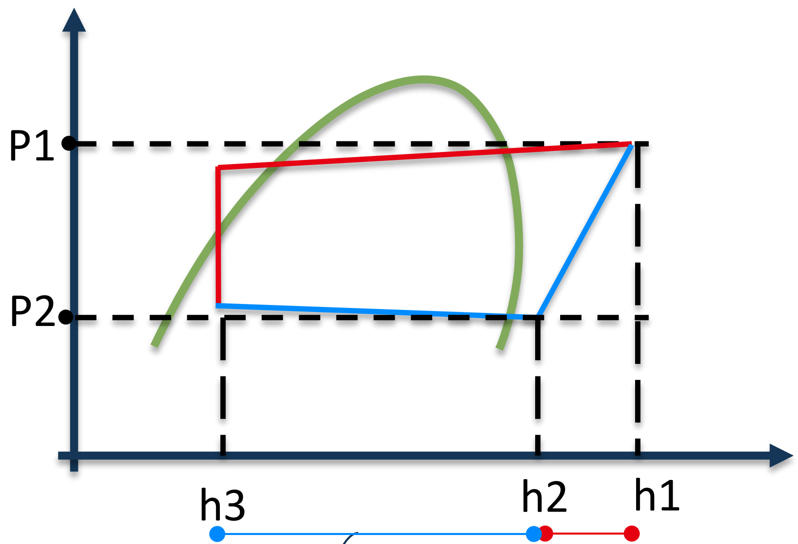




Actual COP =



WHAT THE CHILLER PERFORMANCE TEST DOES

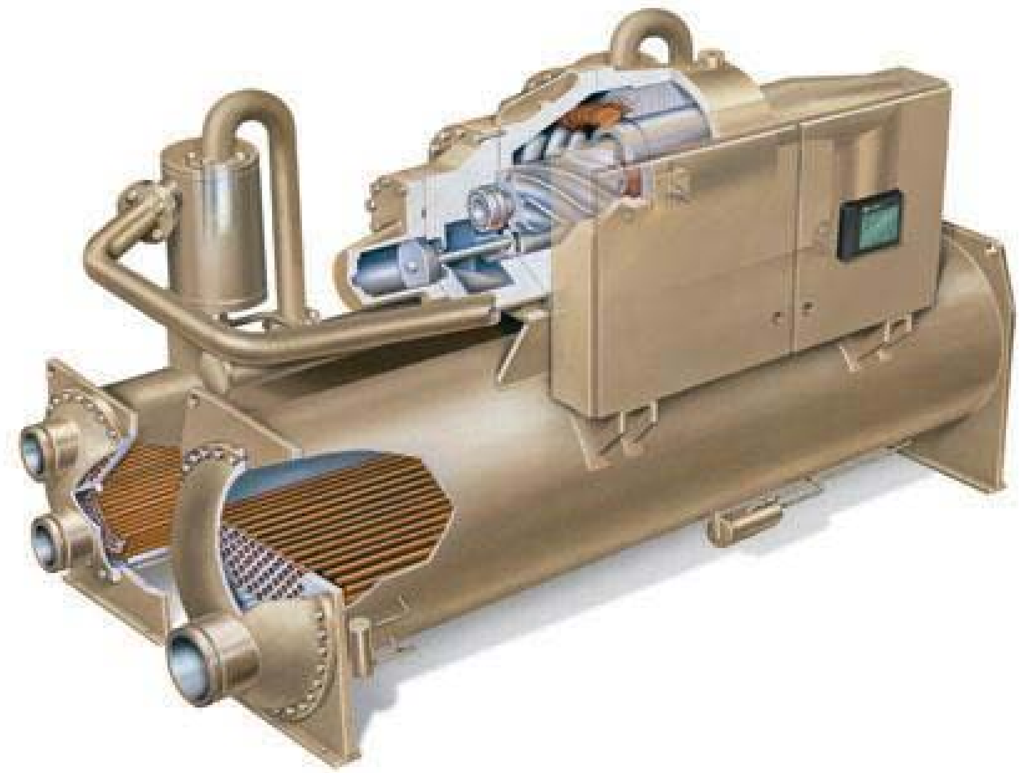


$$\text{Actual COP} = \frac{h1 - h2}{h2 - h3} \qquad \frac{\text{kW}}{\text{TON}}$$

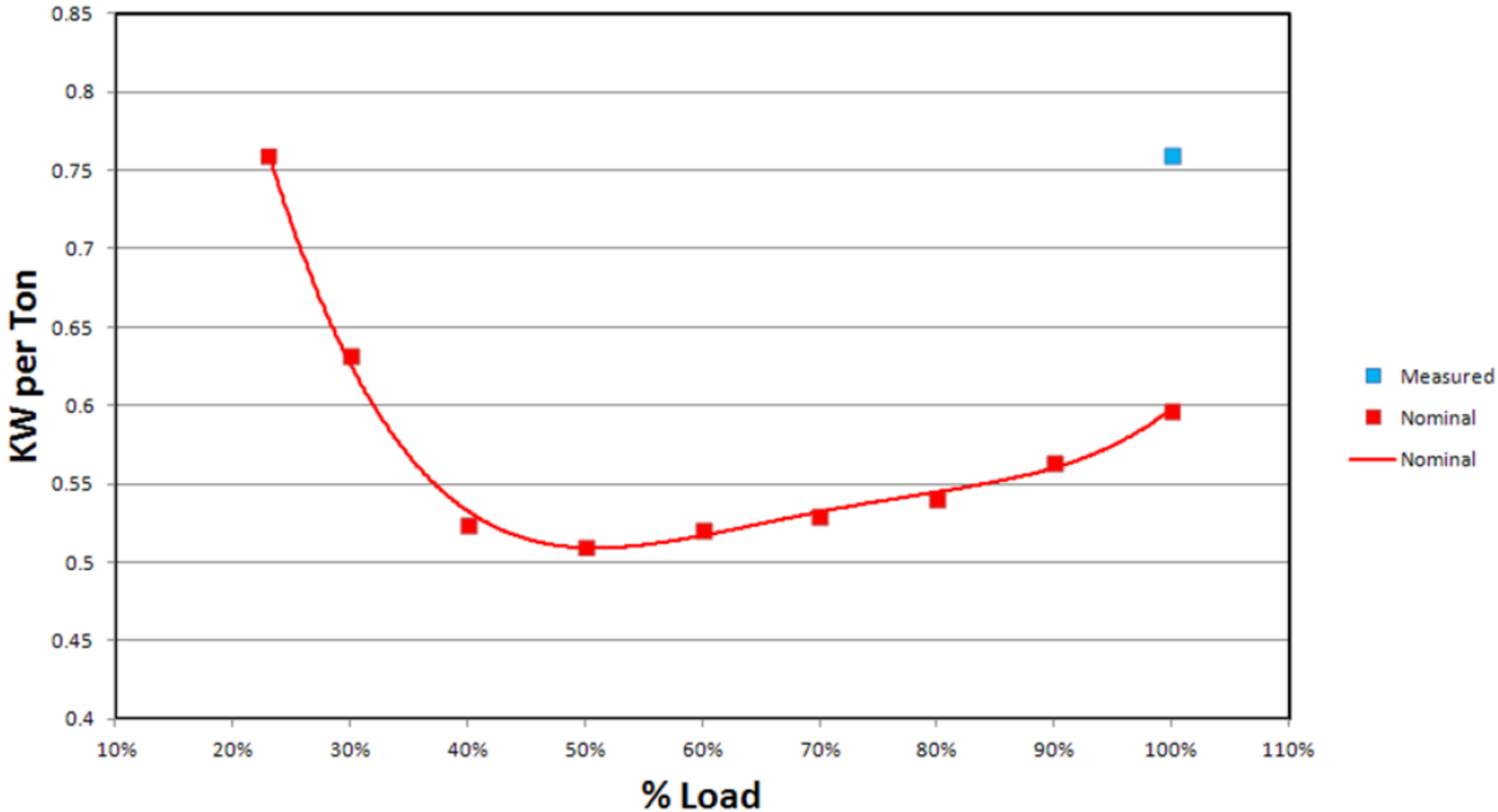
1ST LOOK INSIDE THE BLACK BOX

- A local manufacturing company that had been aggressively executing efficiency projects and doing maintenance
- Looking for more effective way to measure performance

180 Ton Water Cooled Screw Chiller



Obvious Degradation in Performance



*Due to the chiller issues measured data was only comparable to nominal data at 100% load.

WHY?

		Nominal Data	Measured Data
Capacity (Tons)		187.8	140
Unit Power (KW)		112.1	109.2
Efficiency (Kw/Ton)		0.597	0.78
Saturated Suction Temp		39.8	33.7
Saturated Condensing Temp		95.4	95
Evap Entering Temp (F)		55.2	56.3
Evap Leaving Temp (F)		44	46.6
Evap approach (F)	(LWTE - SST)	4.2	12.9
Cond Entering Temp (F)		80	80.1
Cond Leaving Temp (F)		90.6	90
Cond approach (F)	(SCT - LWTC)	4.8	5
Discharge Temp (F)		114.4	116.6
Discharge Superheat	(DT - SCT)	17.2	21.6

* Nominal Data was provided by Trane
* Measurements were done with system at 100% load
* See Appendix Table 1:1

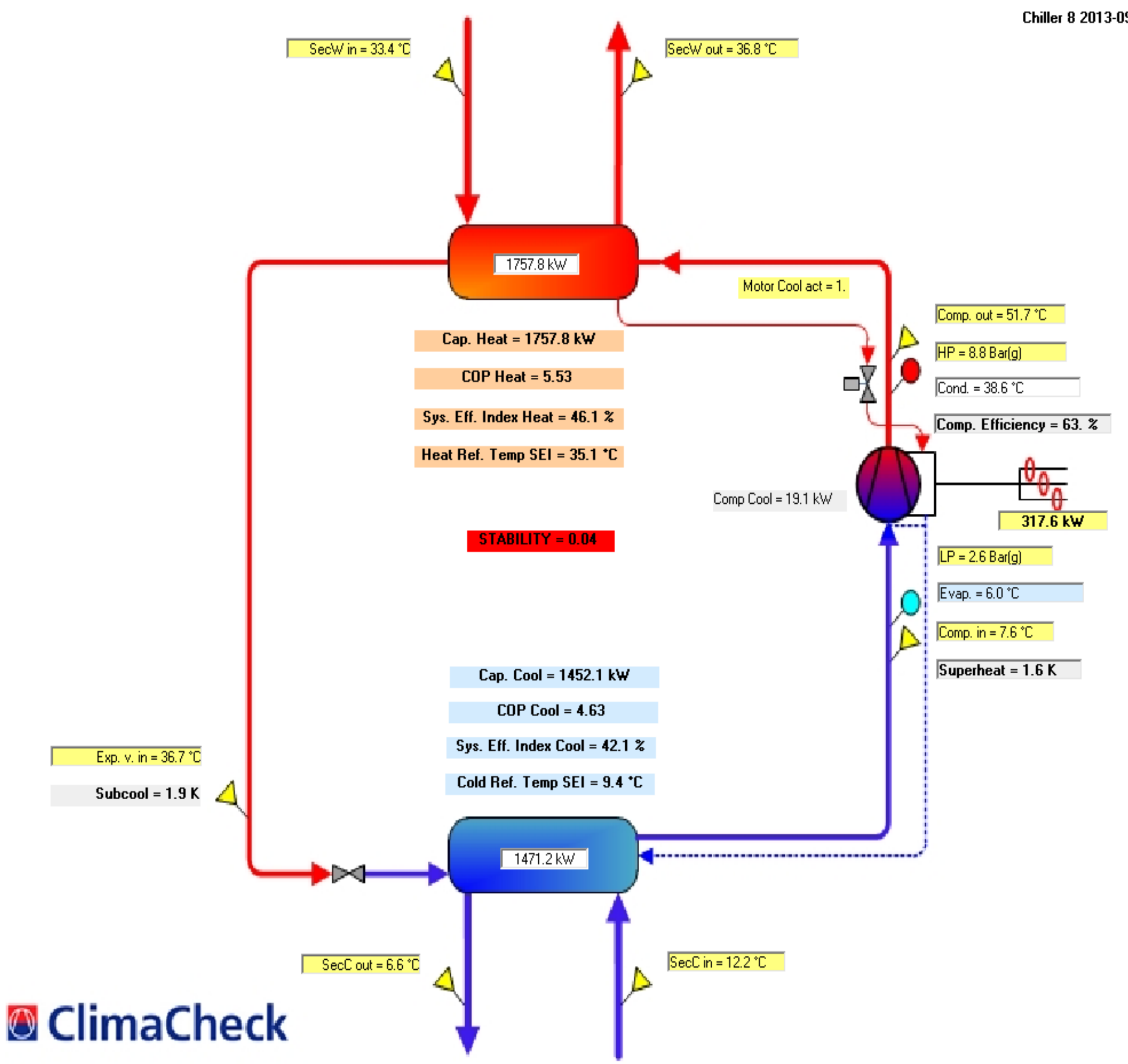
Data suggests evaporator problems

2-3% power gain / 1°F drop in refrigerant temp

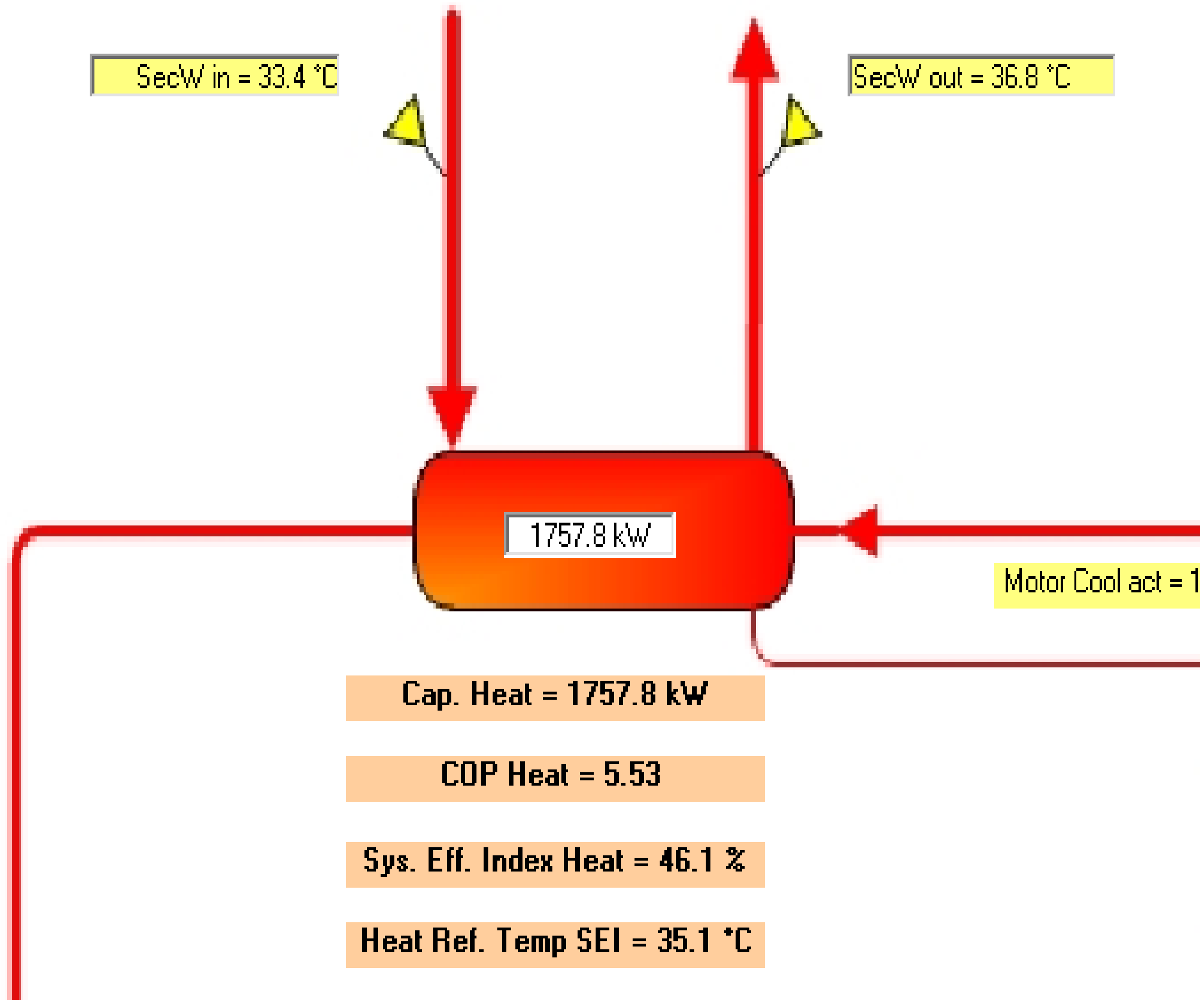
Answer

- 2x the Required Oil in the Evaporator
  - Compressor had been replaced. Technician added recommended amount of oil, overfilling the chiller because of existing oil.
  - Excess oil coating the tubes acts as an insulator, requiring chiller to make colder refrigerant to deliver necessary cooling, increasing energy.

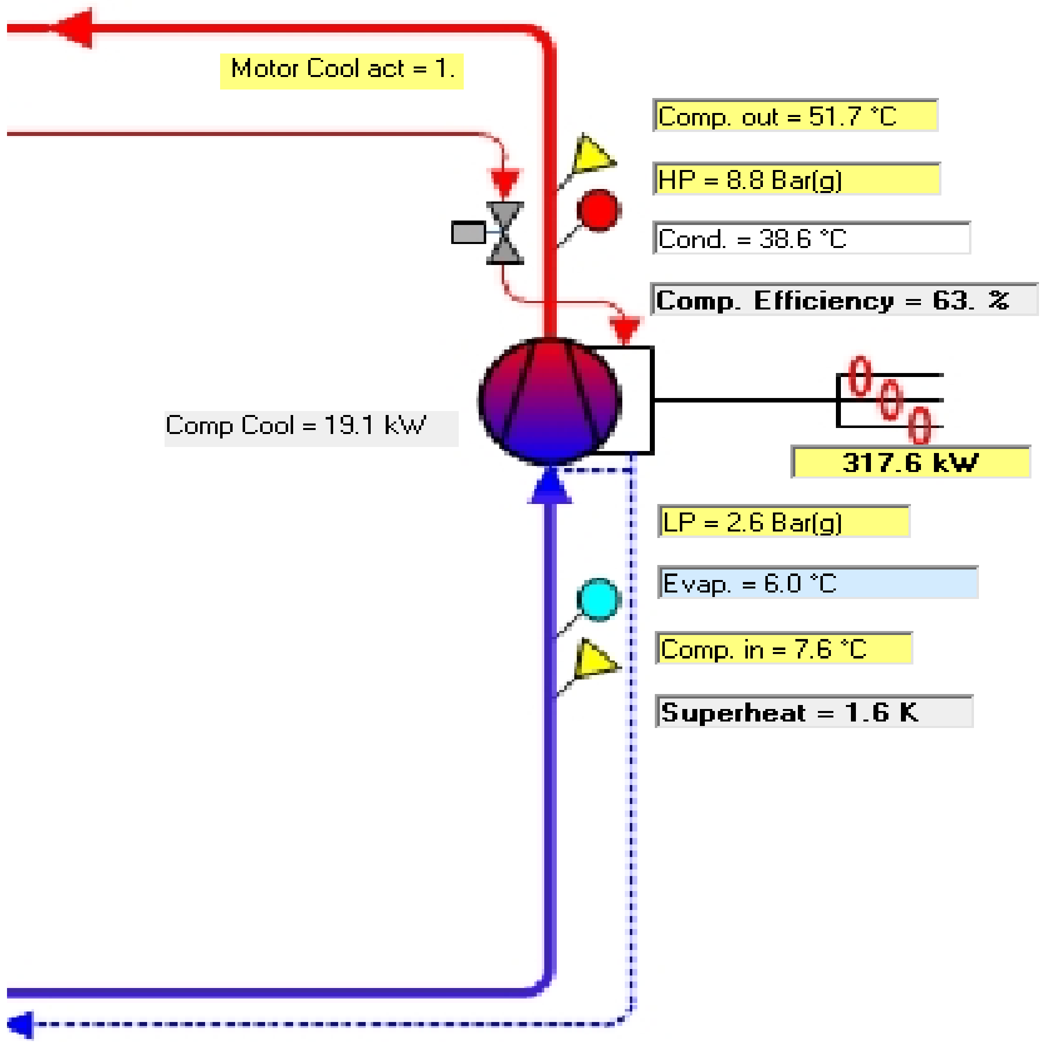
ClimaCheck Flow Chart Overview



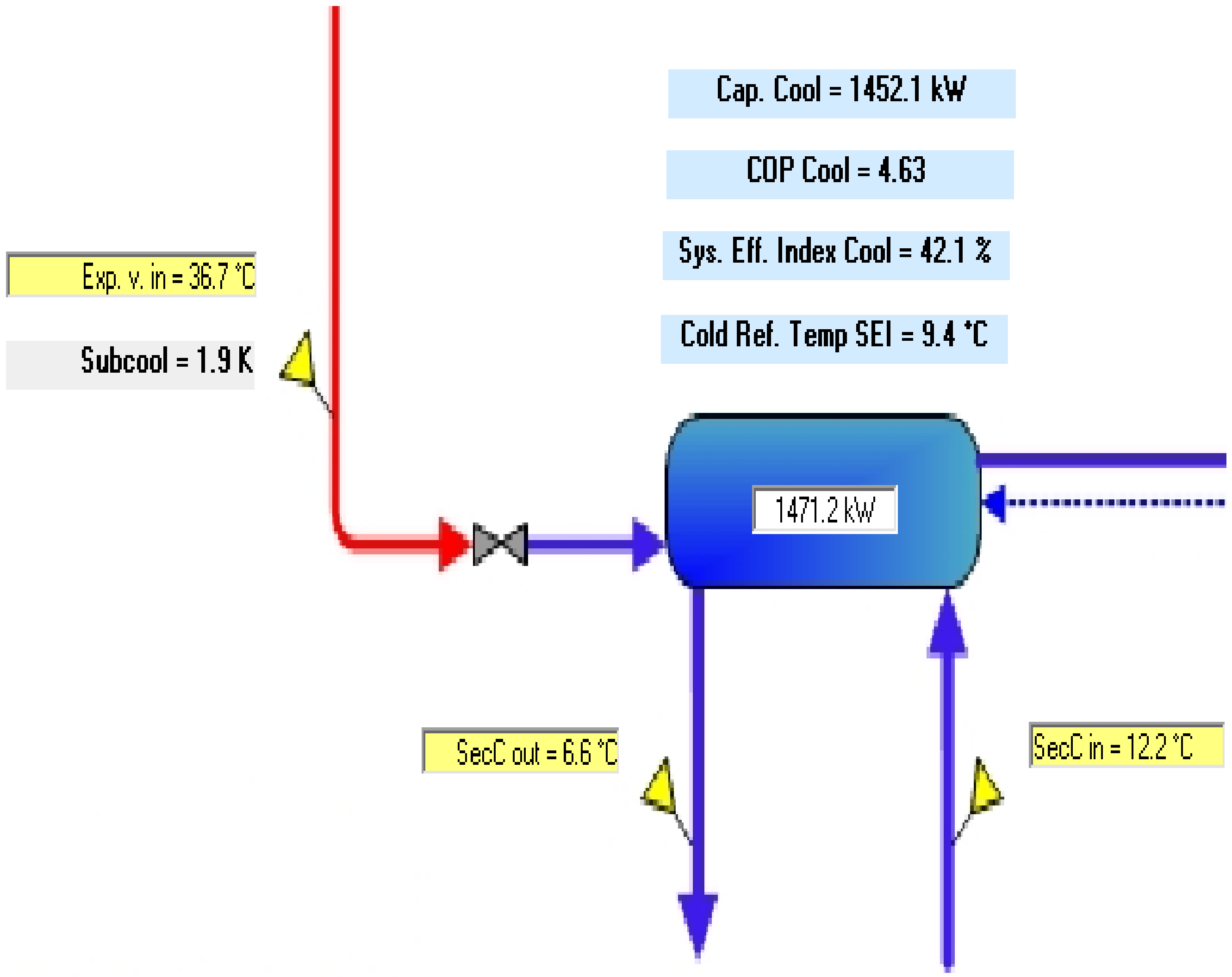
ClimaCheck (Condenser)



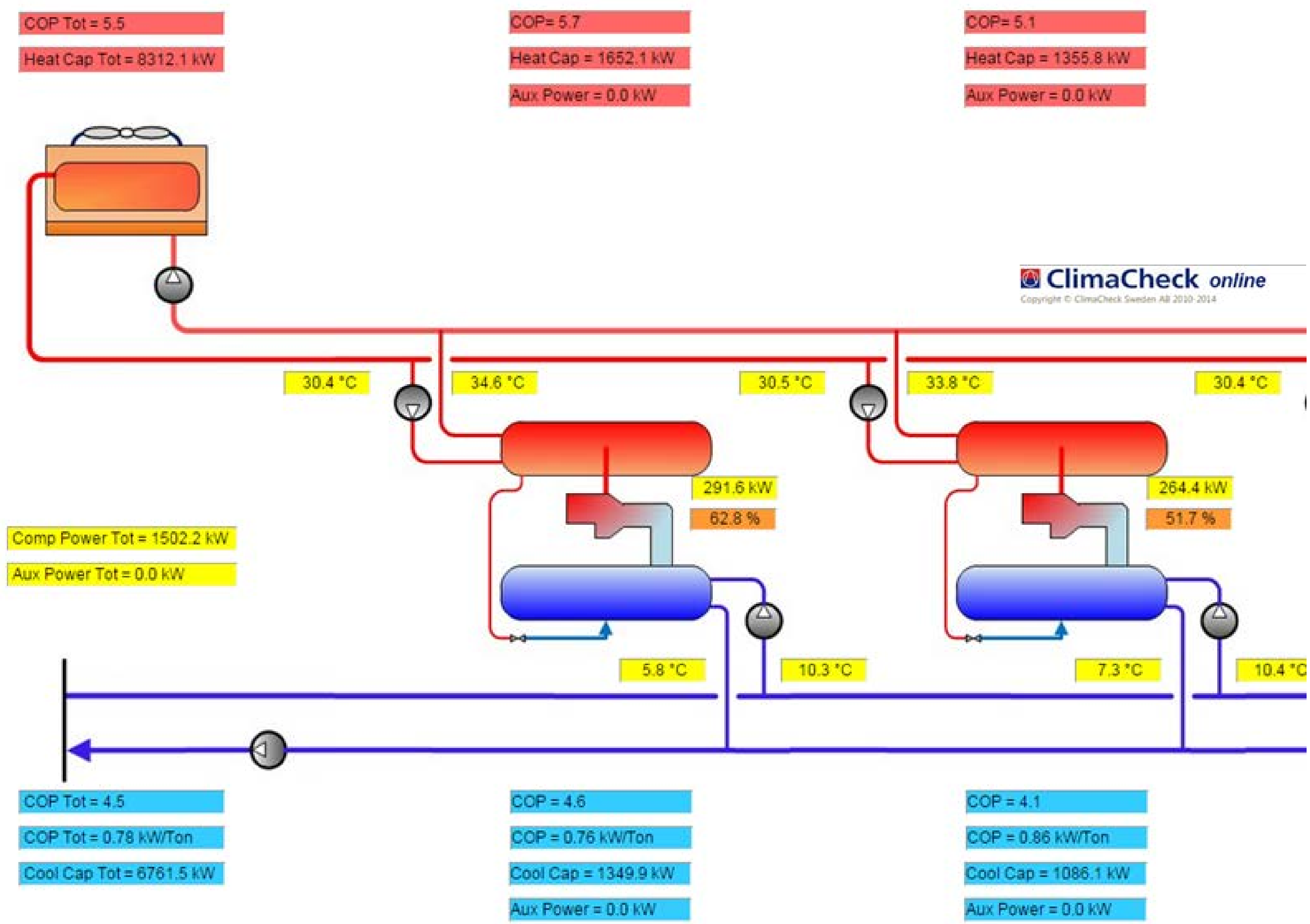
ClimaCheck (Compressor)



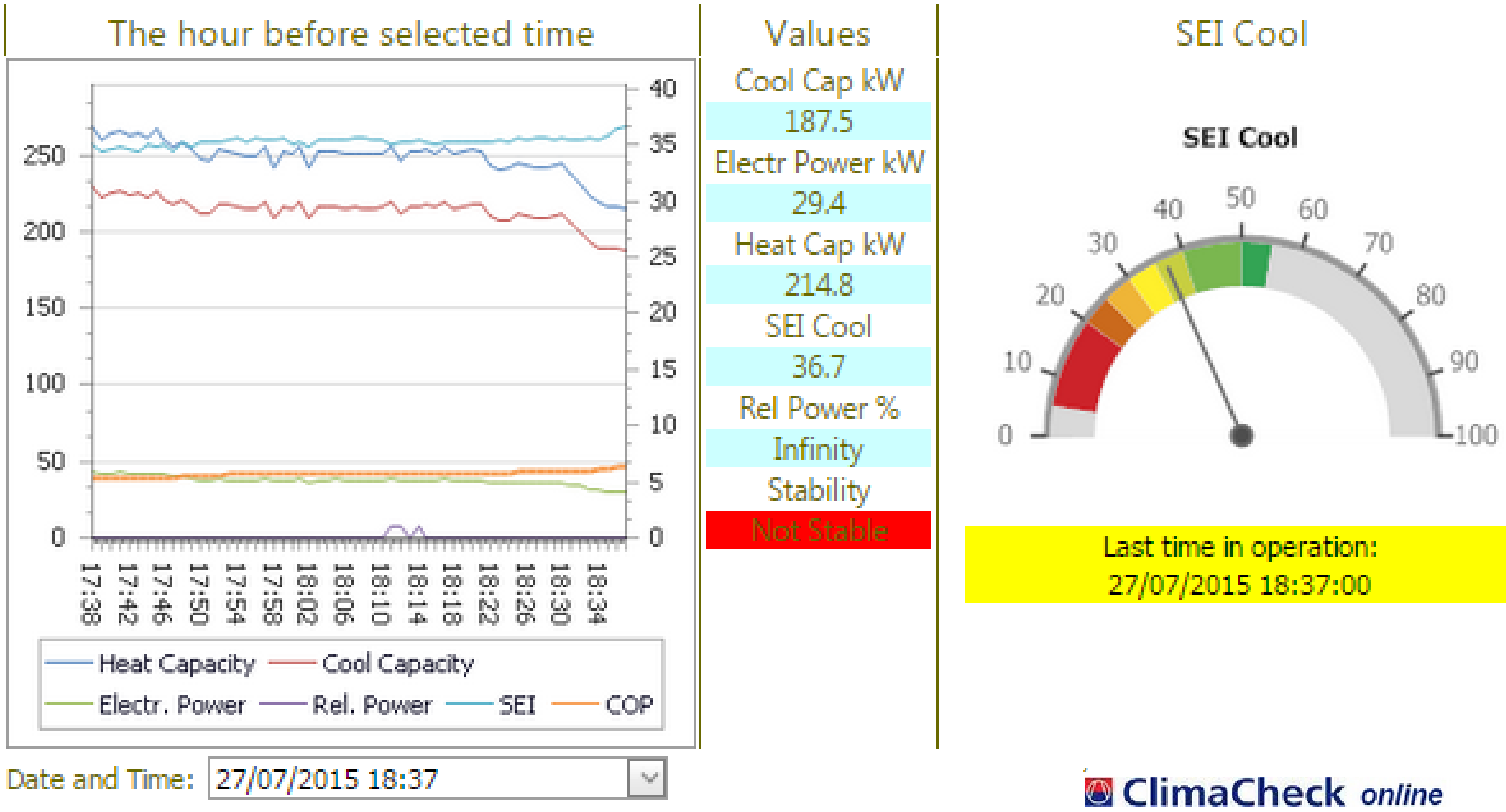
CLIMACHECK (EVAPORATOR)



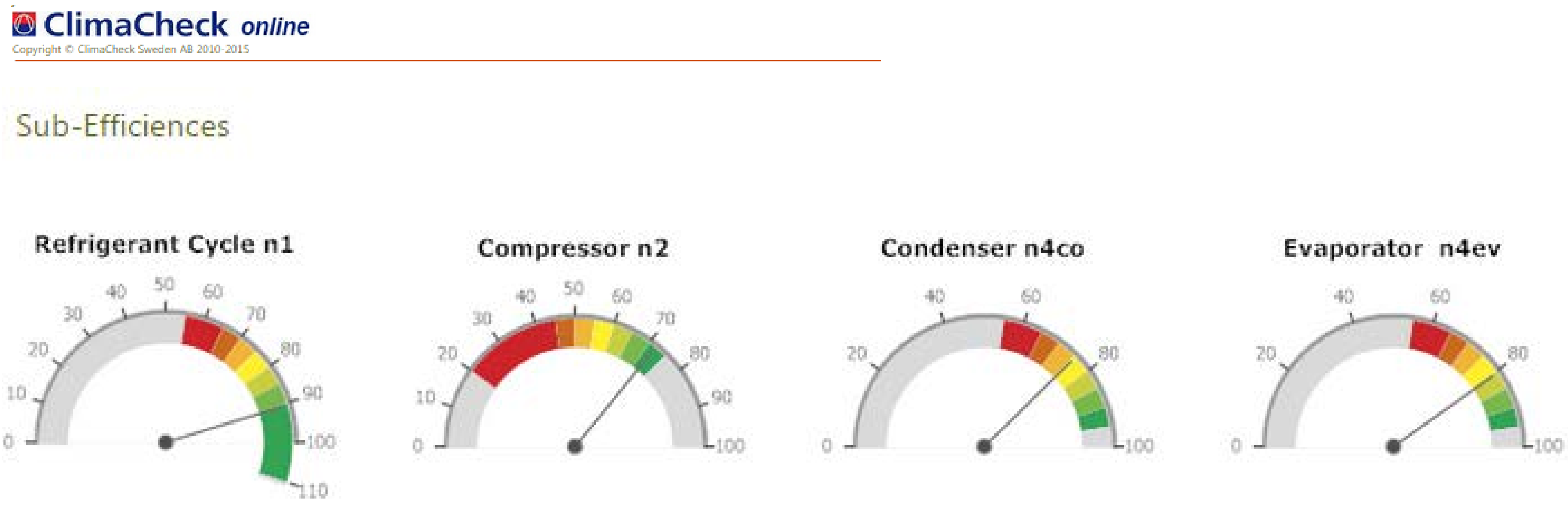
ONLINE BENCHMARKING



STATE OF THE ART CHILLER OPERATING INEFFICIENTLY



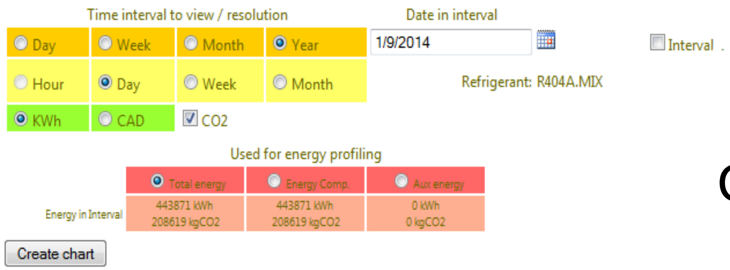
State of the Art Chiller Operating Inefficiently



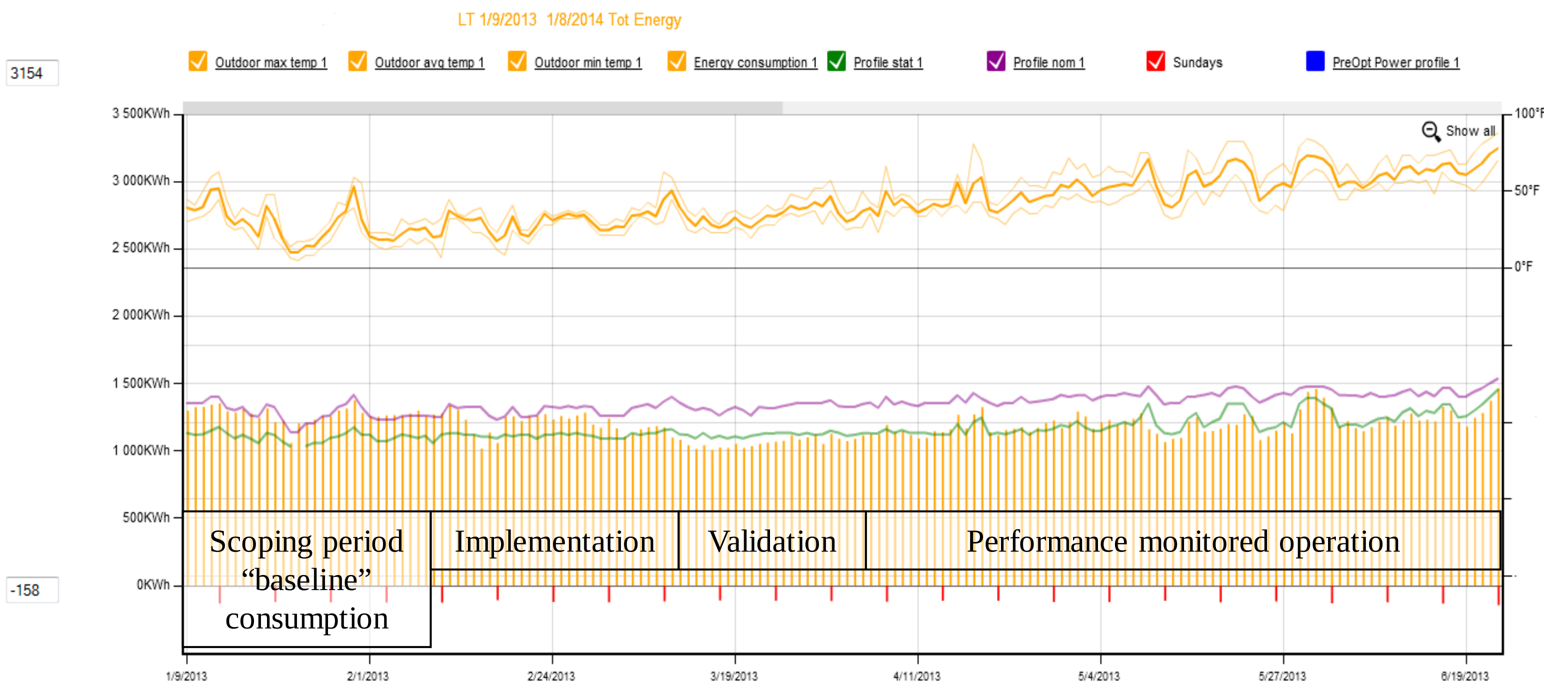
30% higher energy consumption

30,000 kWh/year wasted energy

KNOW THE PERFORMANCE – MAXIMIZE EFFICIENCY



Optimization



Re-Commissioning - result of structured optimisation

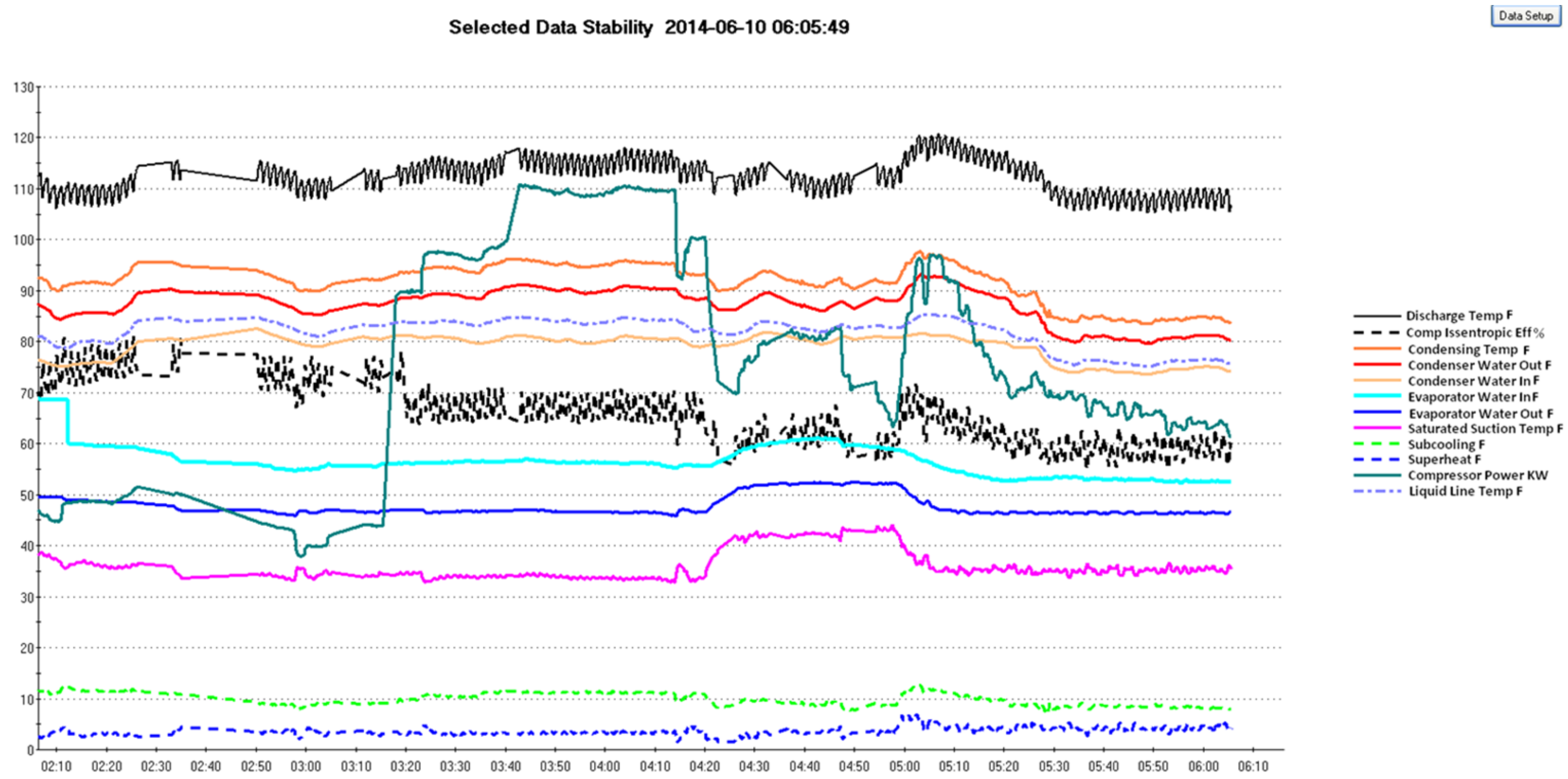
All The Data You Need

21	Date	Time	SecC Evap A in (°F)	SecC Evap A out (°F)	SecC Evap A dT (°F)	Ref Low press. A (PSI(g))	Ref Evap Midpoint A (°F)	Ref Comp A in (°F)	Super heat A (°F)	SecW Cond A in (°F)	SecW Cond A out (°F)	SecW Cond A dT (°F)	Ref High press. A (PSI(g))	Ref Cond Mid point A (°F)	Ref Cond. A out (°F)	Sub Cool Cond A out (°F)	Ref Exp. Valve A in (°F)	Sub cool total A (°F)	Ref Comp A out (°F)	Comp Isen. eff** A (%)	Power input Comp. A (kW)	COP Cool A	Cap. Cool A (kW)	SecC Flow A (kg/s)	Liq Cool Comp (RT)	Cap. Cool A (RT)	Effic. Cool A (kW/RT)
1067	2014-06-10	04:00:55	56.1	46.6	9.5	29.21	33.7	37.0	3.4	80.2	90.1	9.9	114.20	95.1	84.0	11.1	84.0	11.1	115.2	66.8	109.3	4.65	507.7	22.9	3.1	144.4	0.76
1068	2014-06-10	04:00:50	56.1	46.6	9.5	29.17	33.6	37.0	3.4	80.2	90.1	9.9	114.12	95.1	84.0	11.1	84.0	11.1	114.8	67.3	109.3	4.68	511.6	23.1	3.1	145.5	0.75
1069	2014-06-10	04:00:45	56.1	46.6	9.5	29.24	33.7	37.0	3.3	80.2	90.1	9.9	114.16	95.1	84.0	11.1	84.0	11.1	114.1	68.2	109.3	4.75	519.5	23.4	3.1	147.7	0.74
1070	2014-06-10	04:00:40	56.1	46.6	9.5	29.24	33.7	37.0	3.3	80.2	90.1	9.9	114.25	95.1	84.0	11.1	84.0	11.1	113.5	69.0	109.3	4.81	525.9	23.7	3.1	149.5	0.73
1071	2014-06-10	04:00:35	56.1	46.6	9.5	29.28	33.7	37.0	3.3	80.2	90.1	9.9	114.25	95.1	84.0	11.1	84.0	11.1	112.8	70.0	109.4	4.89	534.3	24.1	3.1	151.9	0.72
1072	2014-06-10	04:00:30	56.1	46.6	9.5	29.40	33.9	37.0	3.2	80.2	90.0	9.7	114.32	95.2	84.0	11.2	84.0	11.2	112.6	70.1	109.4	4.90	536.1	24.2	3.1	152.4	0.72
1073	2014-06-10	04:00:25	56.1	46.6	9.5	29.49	34.0	37.0	3.1	80.1	90.0	9.9	114.45	95.2	84.0	11.2	84.0	11.2	113.0	69.5	109.4	4.86	532.2	24.0	3.1	151.3	0.72
1074	2014-06-10	04:00:20	56.1	46.6	9.5	29.52	34.0	37.0	3.0	80.1	90.0	9.9	114.52	95.3	84.0	11.3	84.0	11.3	113.9	68.2	109.4	4.77	521.9	23.5	3.1	148.4	0.74
1075	2014-06-10	04:00:15	56.1	46.6	9.5	29.41	33.9	37.0	3.2	80.1	90.0	9.9	114.48	95.3	83.8	11.4	83.8	11.4	115.3	66.3	109.4	4.63	506.6	22.8	3.1	144.1	0.76
1076	2014-06-10	04:00:10	56.3	46.6	9.7	29.40	33.9	37.0	3.2	80.1	90.0	9.9	114.36	95.2	83.8	11.4	83.8	11.4	116.2	65.1	109.4	4.54	497.0	22.0	3.1	141.3	0.77
1077	2014-06-10	04:00:05	56.3	46.6	9.7	29.24	33.7	37.0	3.3	80.1	90.0	9.9	114.20	95.1	83.8	11.3	83.8	11.3	116.8	64.5	109.2	4.50	490.9	21.7	3.1	139.6	0.78
1078	2014-06-10	04:00:00	56.3	46.6	9.7	29.24	33.7	37.0	3.3	80.1	90.0	9.9	114.00	95.0	83.8	11.2	83.8	11.2	116.6	64.6	109.2	4.51	492.2	21.8	3.1	140.0	0.78
1079	2014-06-10	03:59:55	56.3	46.6	9.7	29.20	33.6	37.0	3.4	80.1	90.0	9.9	114.00	95.0	83.8	11.2	83.8	11.2	116.4	64.9	109.2	4.53	494.2	21.9	3.1	140.5	0.78
1080	2014-06-10	03:59:50	56.1	46.6	9.5	29.18	33.6	37.0	3.4	80.1	90.0	9.9	113.93	95.0	83.8	11.1	83.8	11.1	116.2	65.2	109.0	4.54	495.4	22.3	3.1	140.9	0.77
1081	2014-06-10	03:59:45	56.1	46.6	9.5	29.14	33.6	37.0	3.5	80.1	90.0	9.9	114.00	95.0	83.8	11.2	83.8	11.2	115.9	65.8	109.0	4.58	499.4	22.5	3.1	142.0	0.77
1082	2014-06-10	03:59:40	56.1	46.6	9.5	29.15	33.6	37.0	3.4	80.1	90.0	9.9	114.00	95.0	83.8	11.2	83.8	11.2	115.5	66.2	108.7	4.61	501.3	22.6	3.1	142.6	0.76
1083	2014-06-10	03:59:35	56.1	46.6	9.5	29.14	33.6	37.0	3.5	80.1	90.0	9.9	113.93	95.0	83.8	11.1	83.8	11.1	115.2	66.7	108.7	4.65	505.0	22.8	3.1	143.6	0.76
1084	2014-06-10	03:59:30	56.1	46.6	9.5	29.05	33.5	37.0	3.6	80.1	90.0	9.9	113.84	94.9	83.8	11.1	83.8	11.1	114.8	67.3	108.9	4.68	510.0	23.0	3.1	145.0	0.75

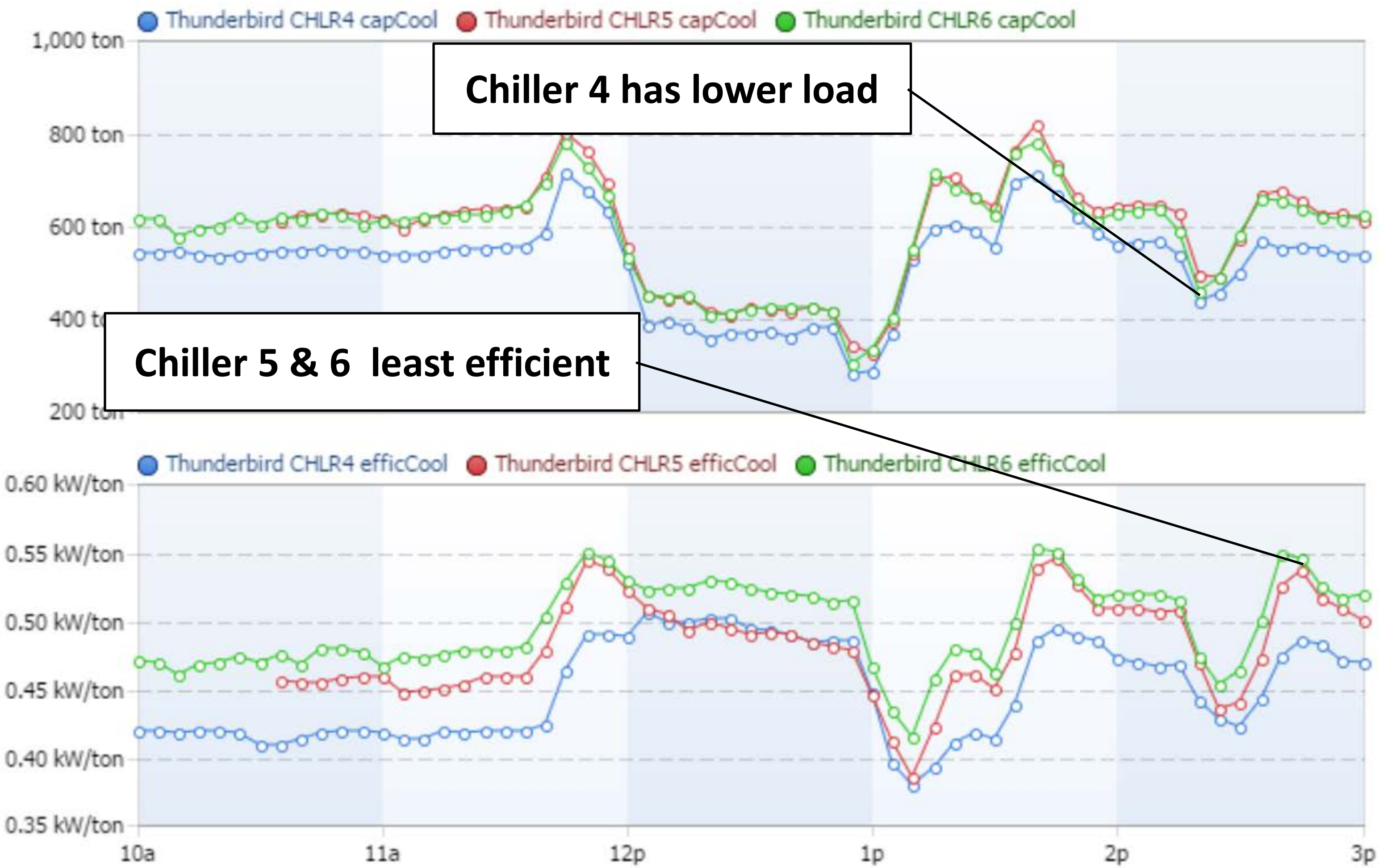
TEST RESULTS FROM ANOTHER 12 CHILLERS

- Low refrigerant
- High refrigerant
- Fouled evaporators / condensers
- Un-balanced flow

Viewing Data With a Familiar Platform

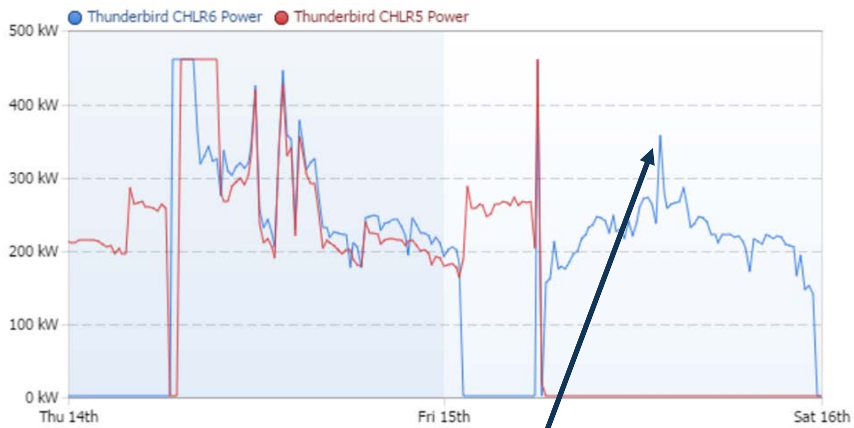


COMPARE MAIN KPIs



Low Refrigerant

Chiller 5 vs 6 before fixes

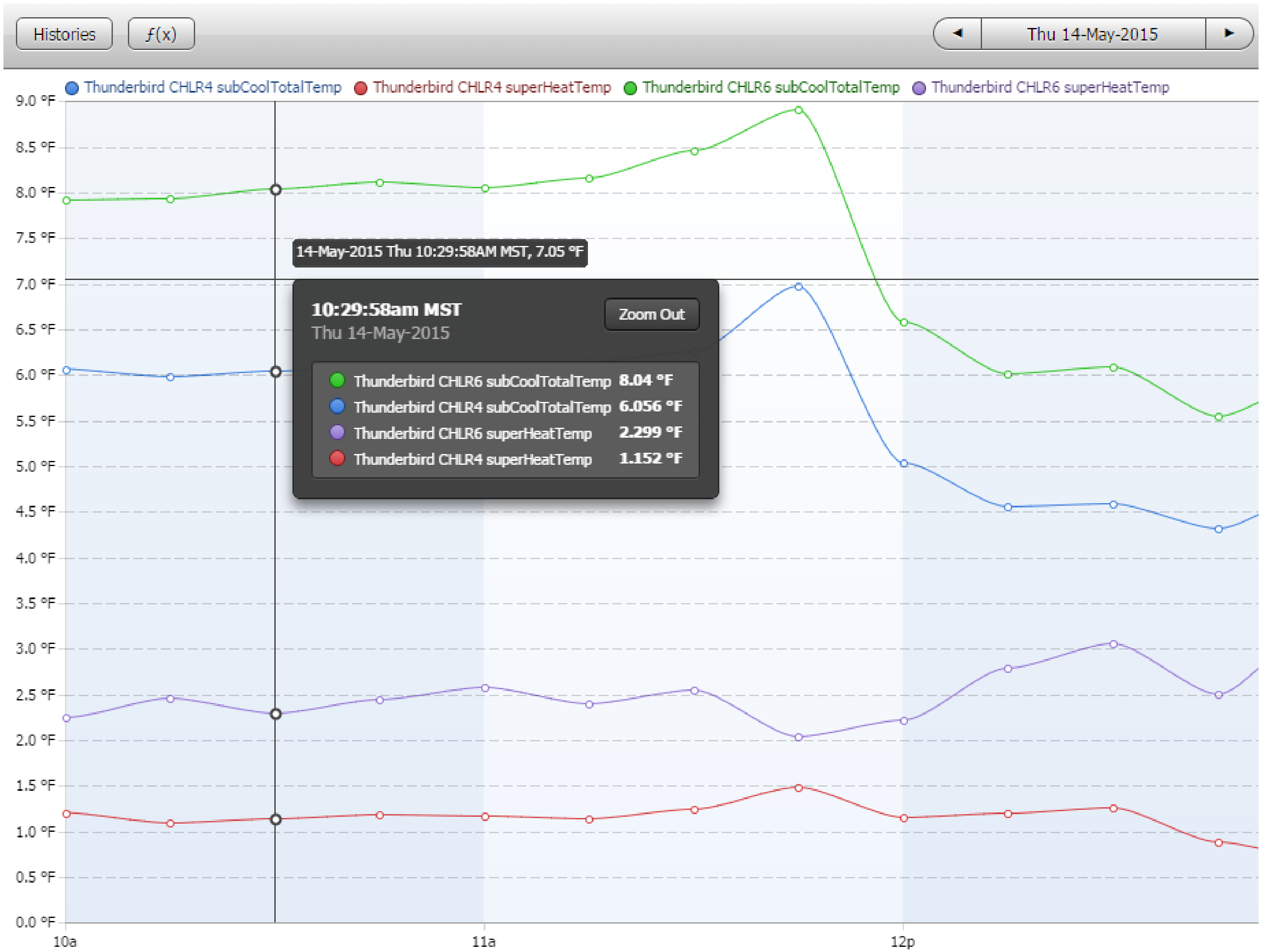


Chiller 6 used more power than Chiller 5

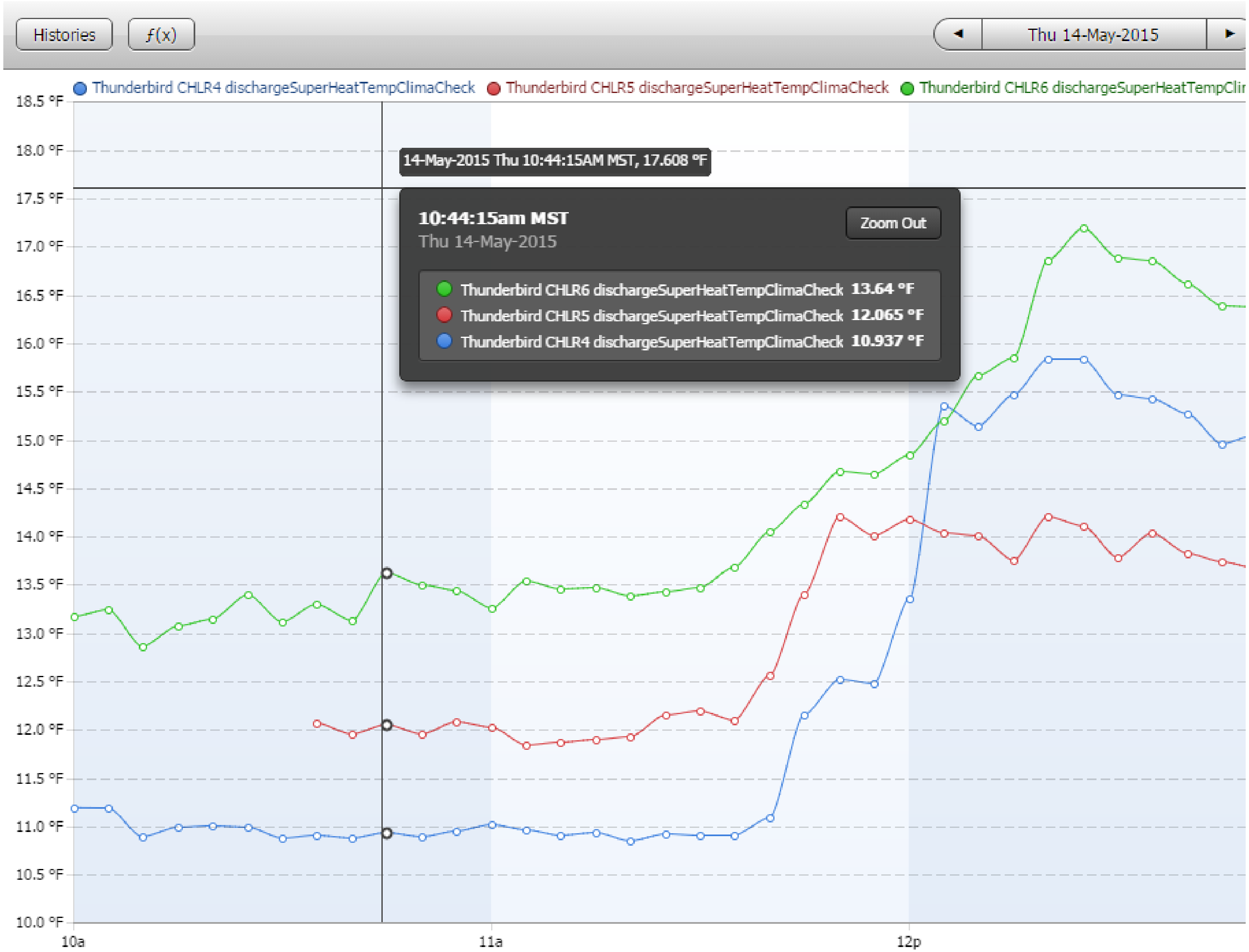
Chiller 6 has refrigerant added

Chillers 5 & 6 used equal power

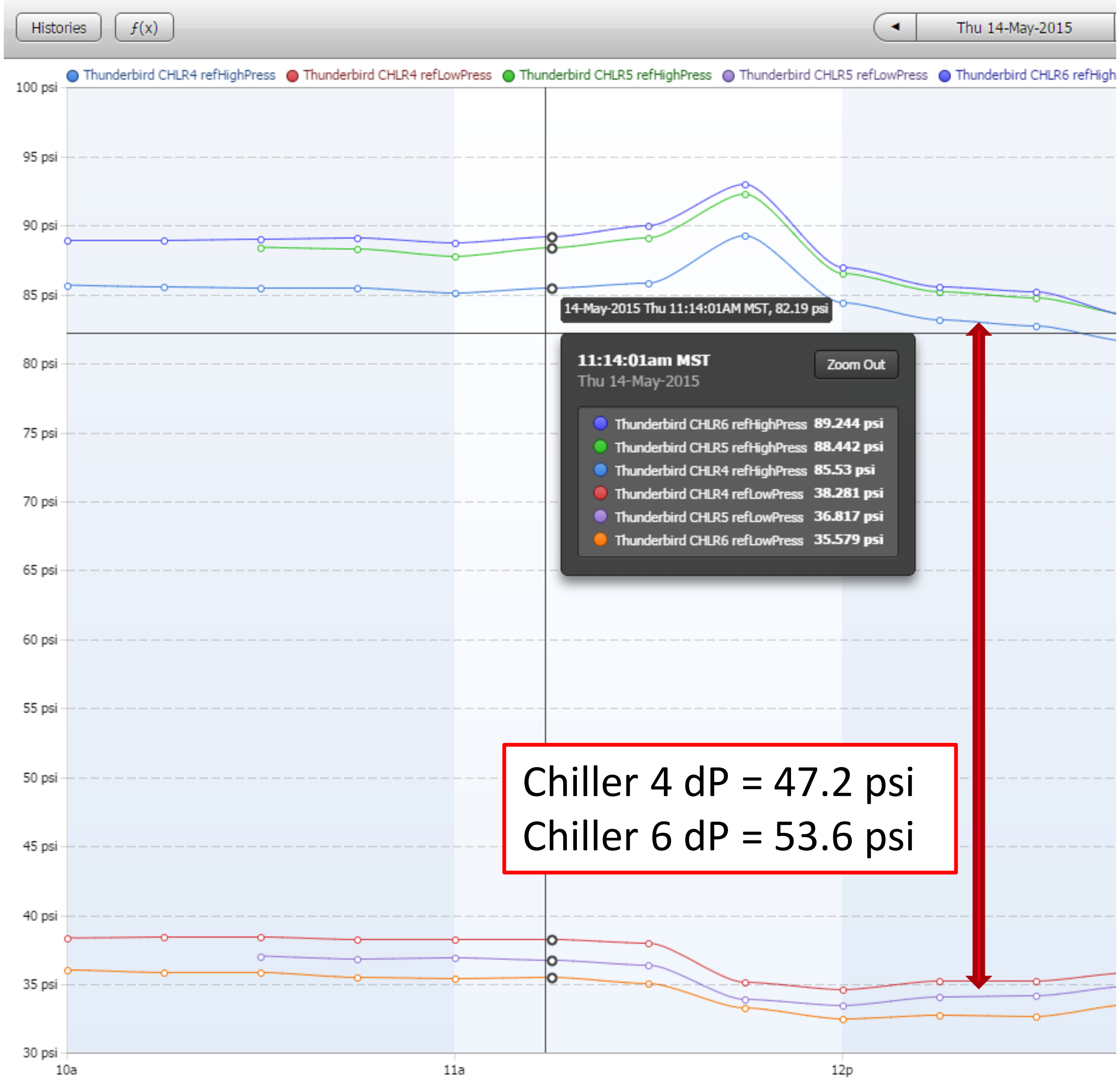
Compare Specific Data Points



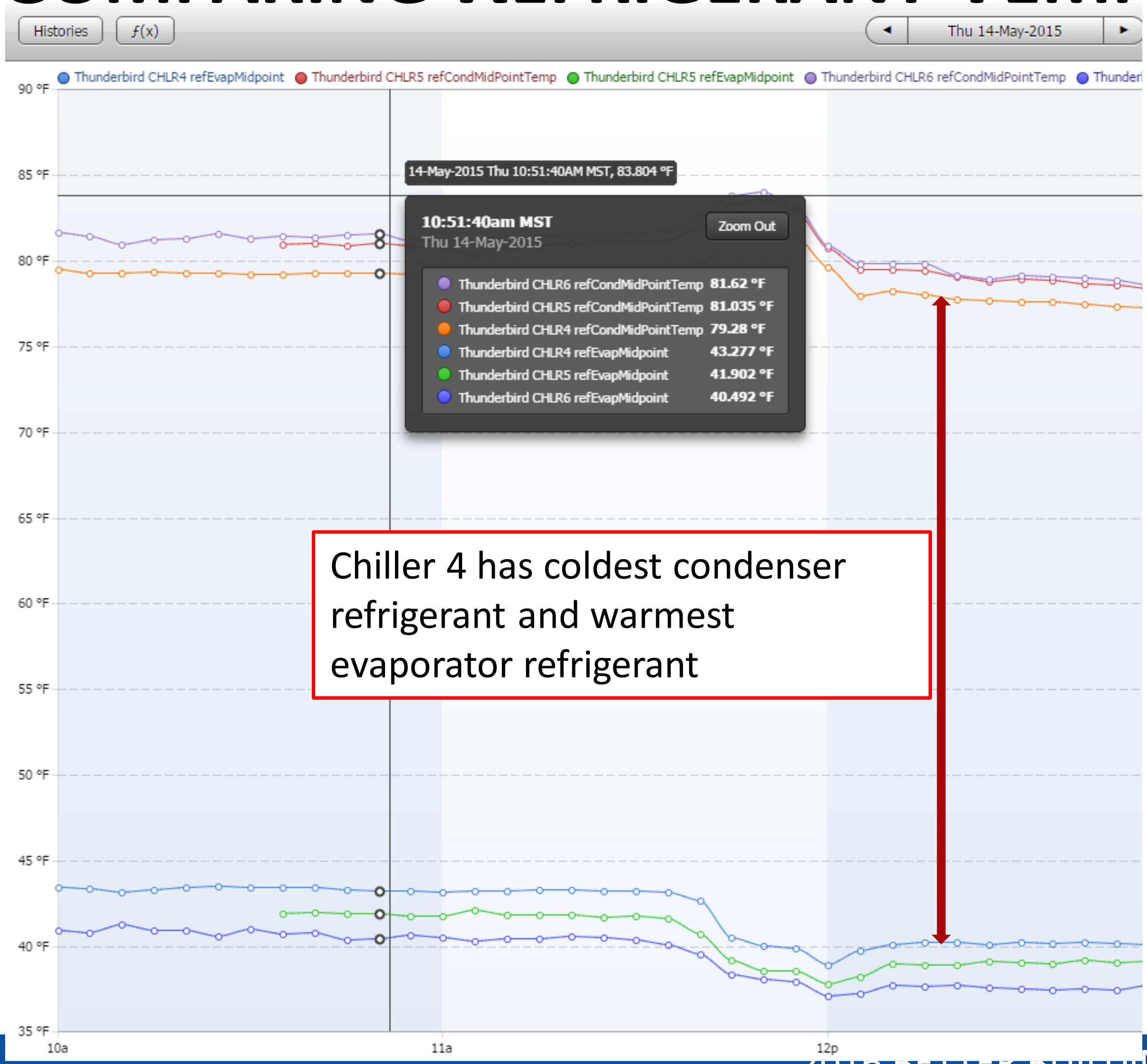
Comparing Data - Superheat



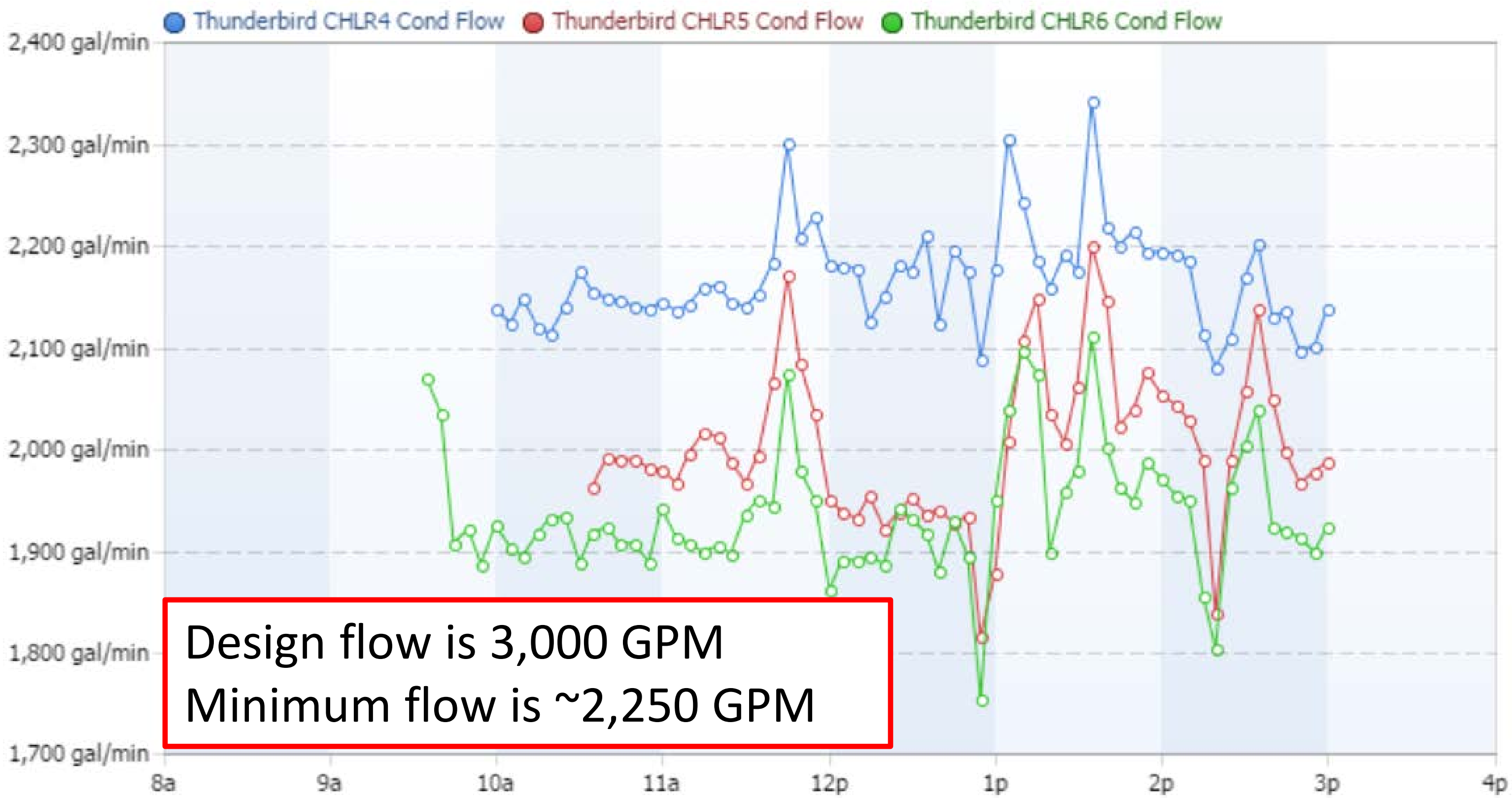
Comparing Refrigerant Pressure



COMPARING REFRIGERANT TEMPS



Zeroing In On the Culprit



Chiller Performance

All-Variable Speed Centrifugal Chiller Plants, Thomas Hartman, ASHRAE Journal, September 2001

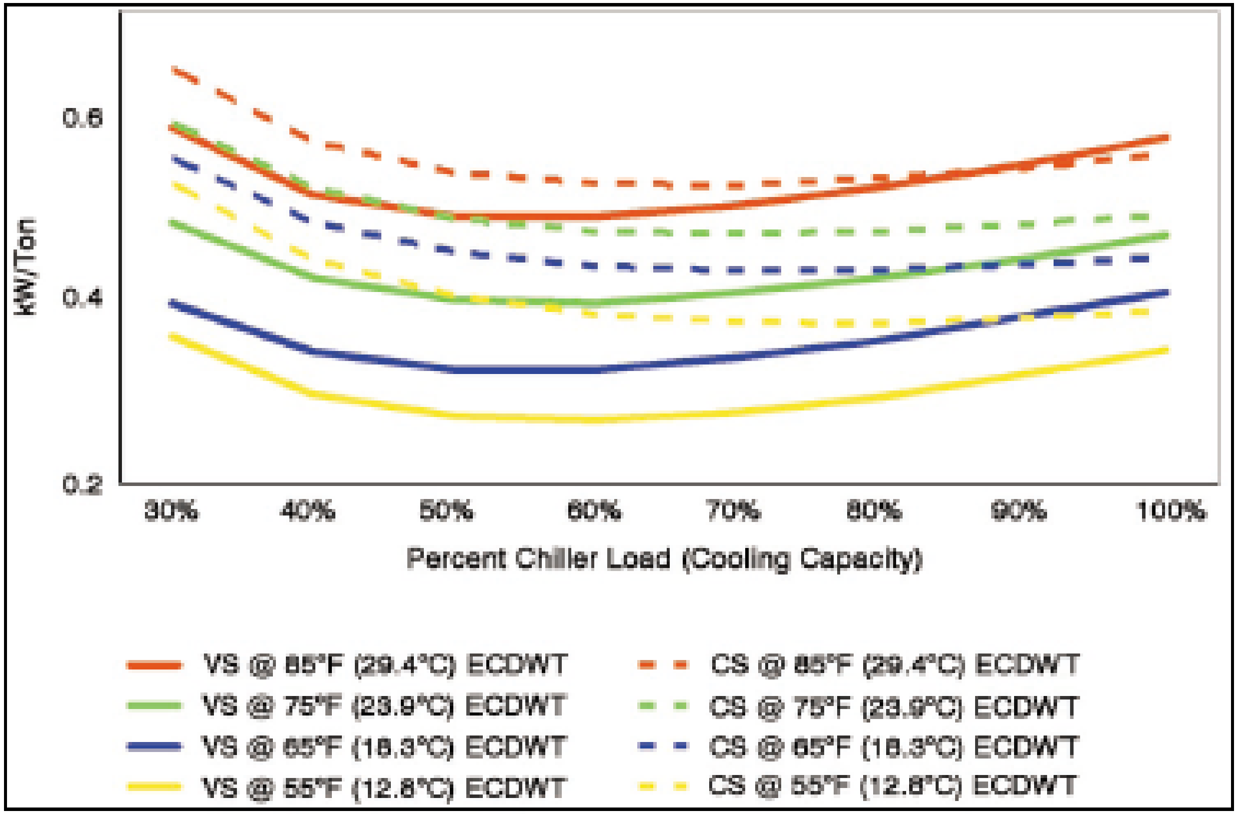
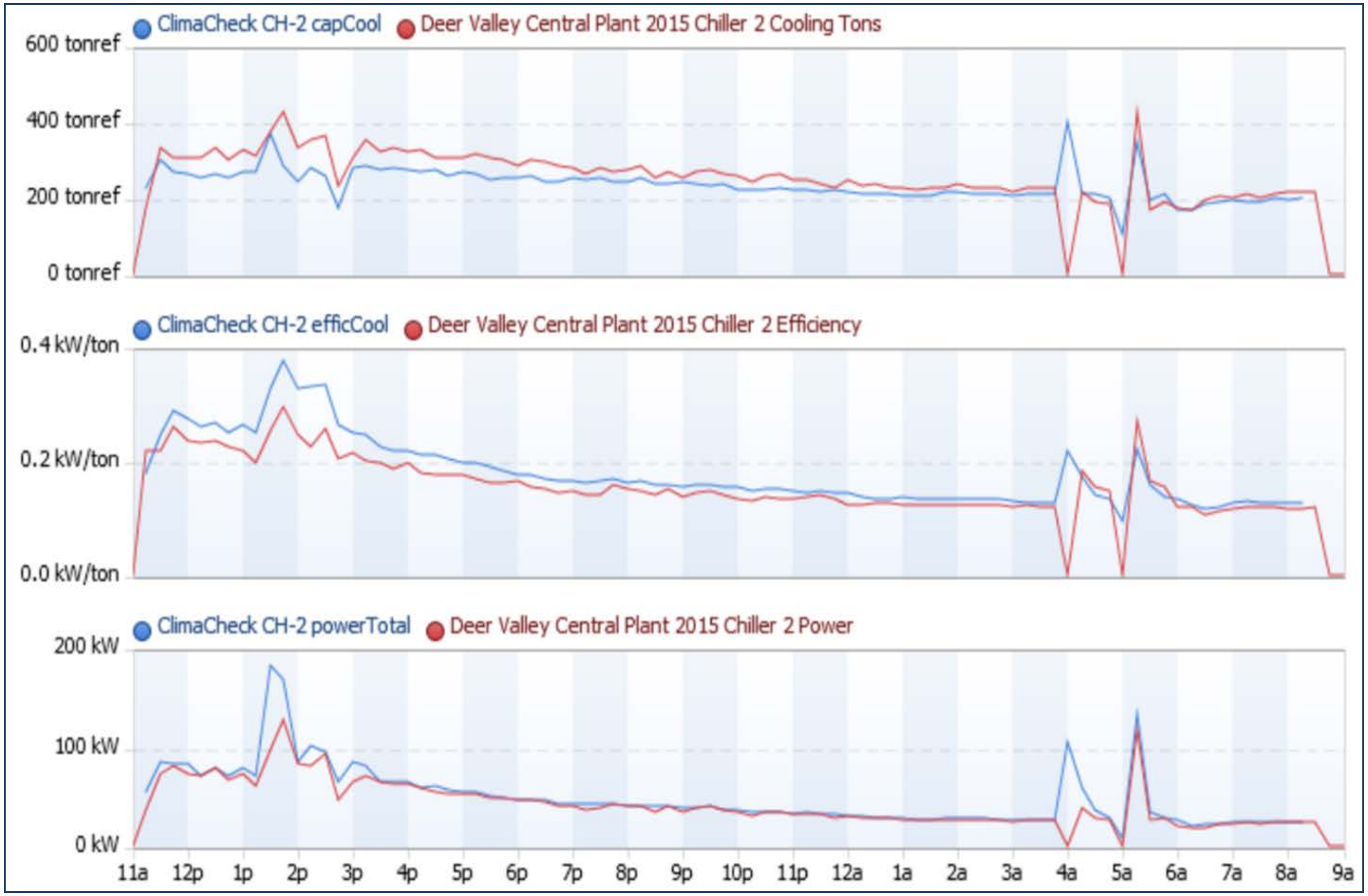


Figure 1: Performance comparison of constant and variable speed centrifugal chiller.

Loads Aren't What You Think

What tonnage do you stage on/off the chillers?



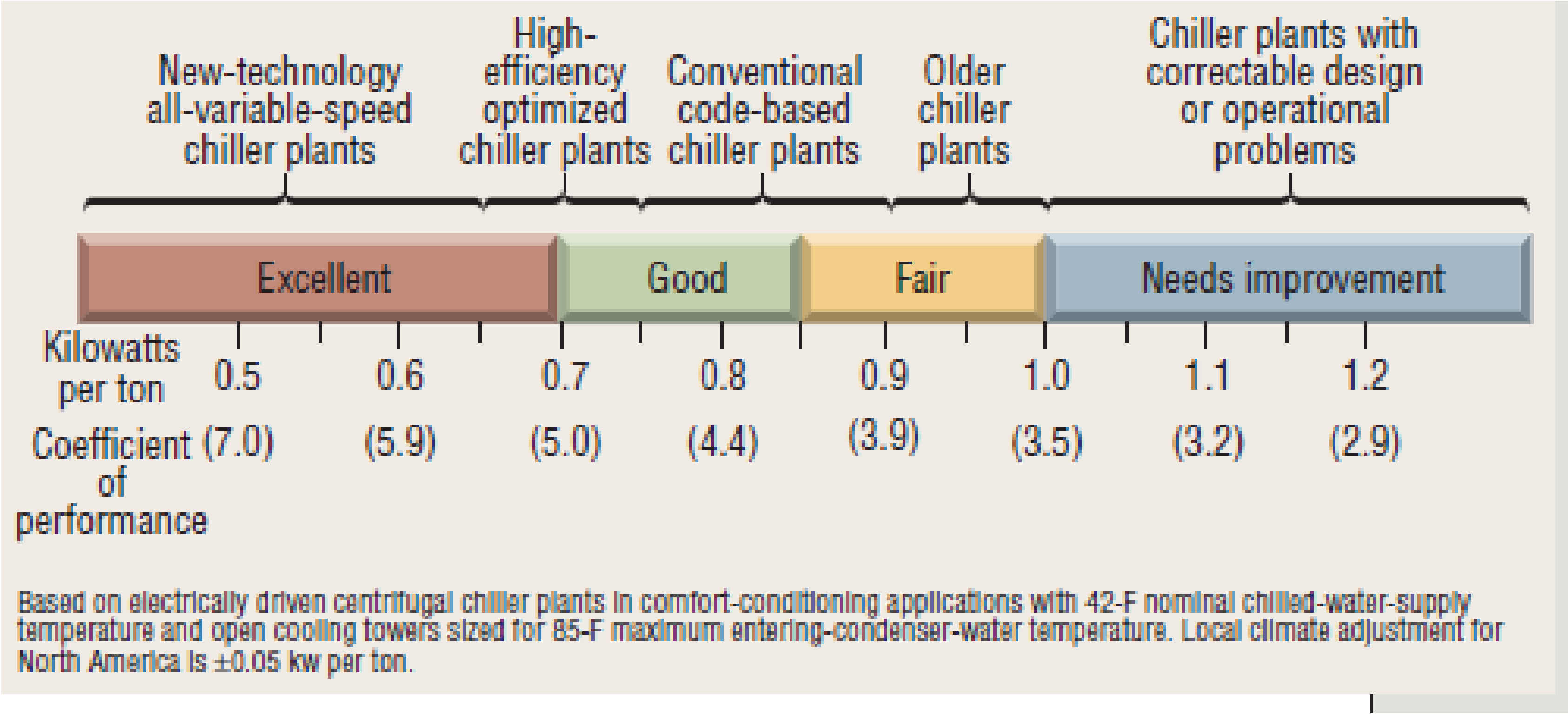
TEST RESULTS SUMMARY

Site	Chiller	# chiller issues	# flow issues	# Other Issues	% Savings
1	1	1			30%
2	3	2			12%
2	5				
2	6	1	1		17%
3	4		1		7%
3	5	2	1		10%
3	6	1	1		18%
4	1	1	1		10%
4	2	1	1		16%
4	3		1		5%
5	1		1	1	5%
5	2		1	1	5%
5	3		1	1	5%

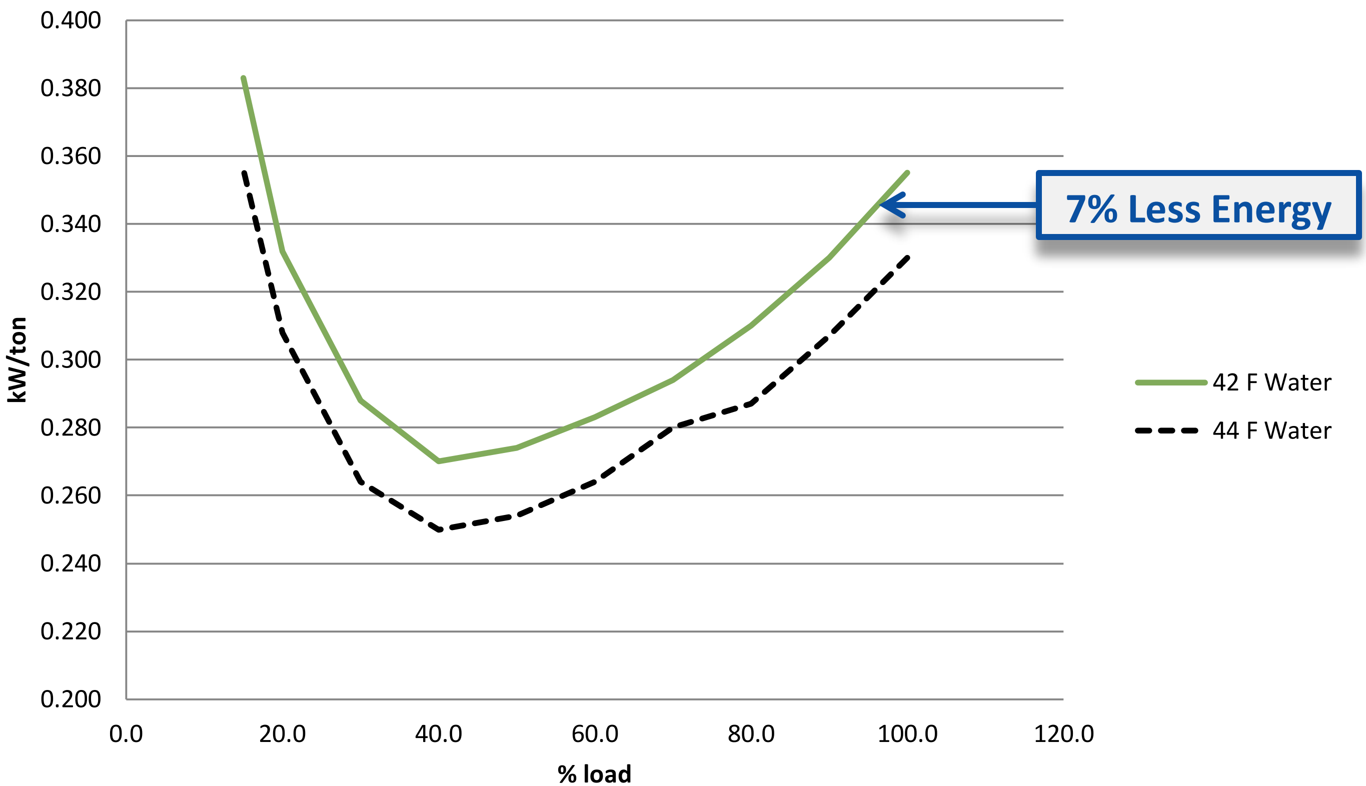
OTHER COOL SLIDES

CHILLER PLANT EFFICIENCIES

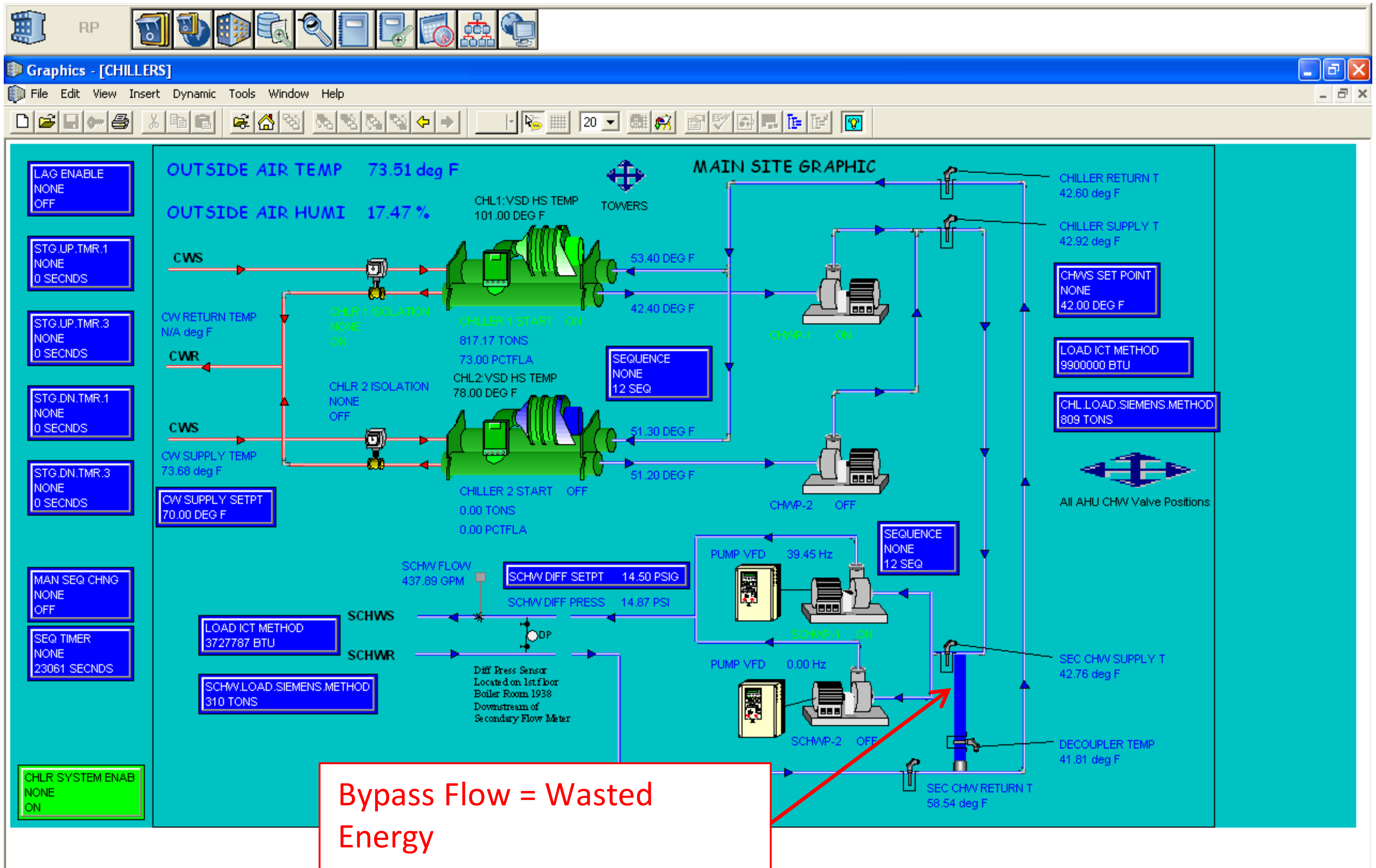
Source: Ultraefficient All-Variable-Speed Chilled Water Plants, Ben Erpelding, HPAC Engineering, March 2006



Chiller Efficiency vs. Temp



PRIMARY/SECONDARY PUMPING



Bypass Flow = Wasted Energy

Bypass Flow – Secondary flow must be < primary flow

Death Spiral

$78,000 savings per year!

QUESTIONS?

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Thank you!

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