Division of Technical Resources
Office of Research Facilities

The National Institutes of Health

The formulae for building state of the art biomedical research facilities.

NIH National Institutes of Health
Turning Discovery Into Health

Informatics Driven Central Plant Optimization

Presented by: Alex Huang, Kayvan Torkashvan, Don Guan

Division of Technical Resources
National Institutes of Health

NIH and What We Do

A federal government agency

Annual research funding ~ $37 billion

27 biomedical research institutes

75 buildings over 300 acres

Total building area~12 million sqft

Houses world-class 240-bed research hospital

NIH Central Utility Plant (CUP) Overview

One of the largest CUPs under one roof in the USA

Provides campus with chilled water, steam, electricity, and compressed air

CUP Components

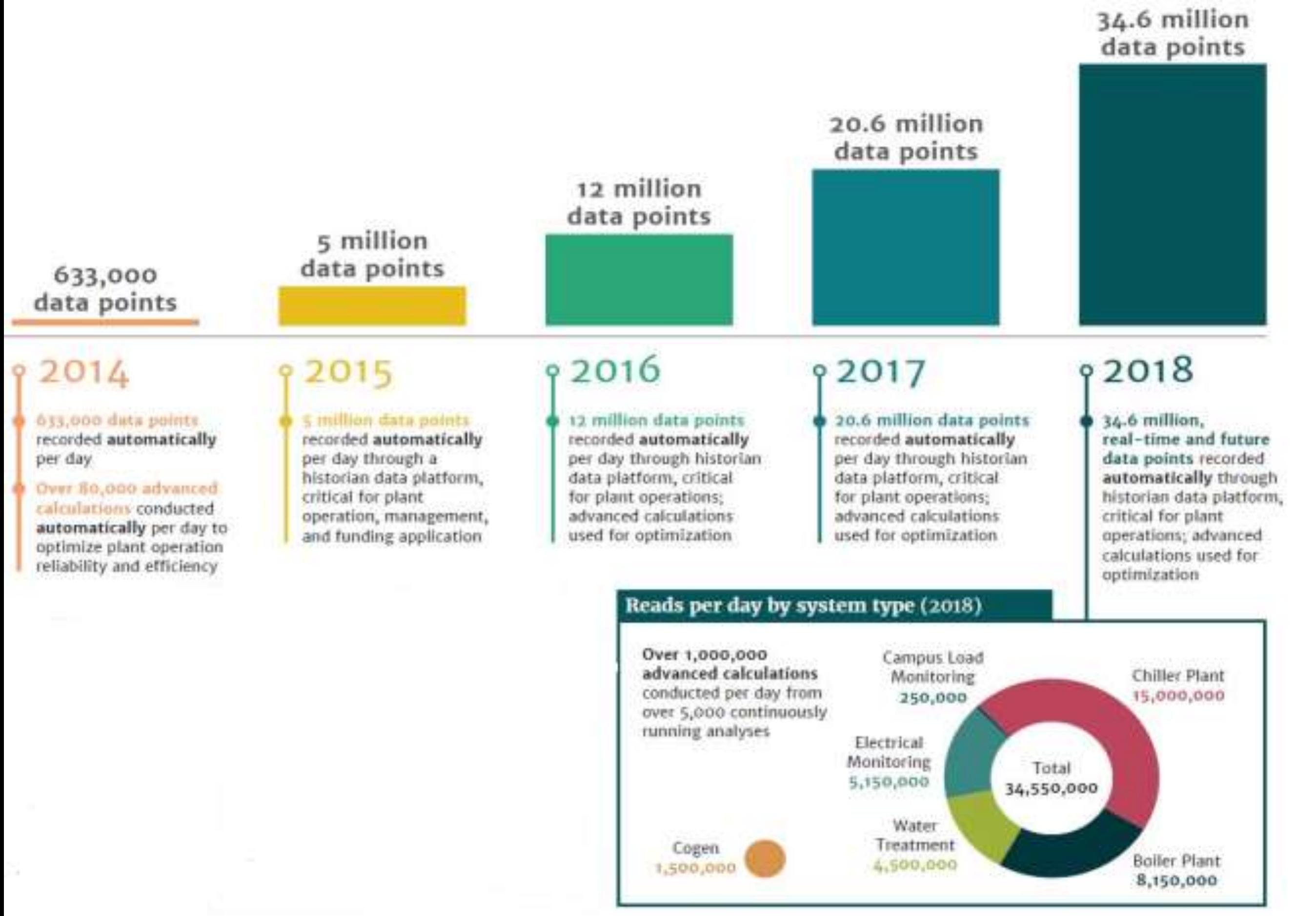
- Twelve 5,000 Ton capacity chillers
- 7.75 million gal CHW thermal storage tank
- 5 million gal Industrial Water System
- Five gas/ diesel dual fuel fired boilers
  - 800 KPPH, 980 KPPH with Cogen
- Cogeneration Power Plant
  - One of the largest US government Cogen plants
  - One of the cleanest Cogen plants in the world
  - 23 MW, 180KPPH steam (40% of campus demand)

TES tank

IWS tank

TES and chiller controls upgrade project presentation will be 3:00 PM today

Data Platform - Heart of Actionable Operational Intelligence

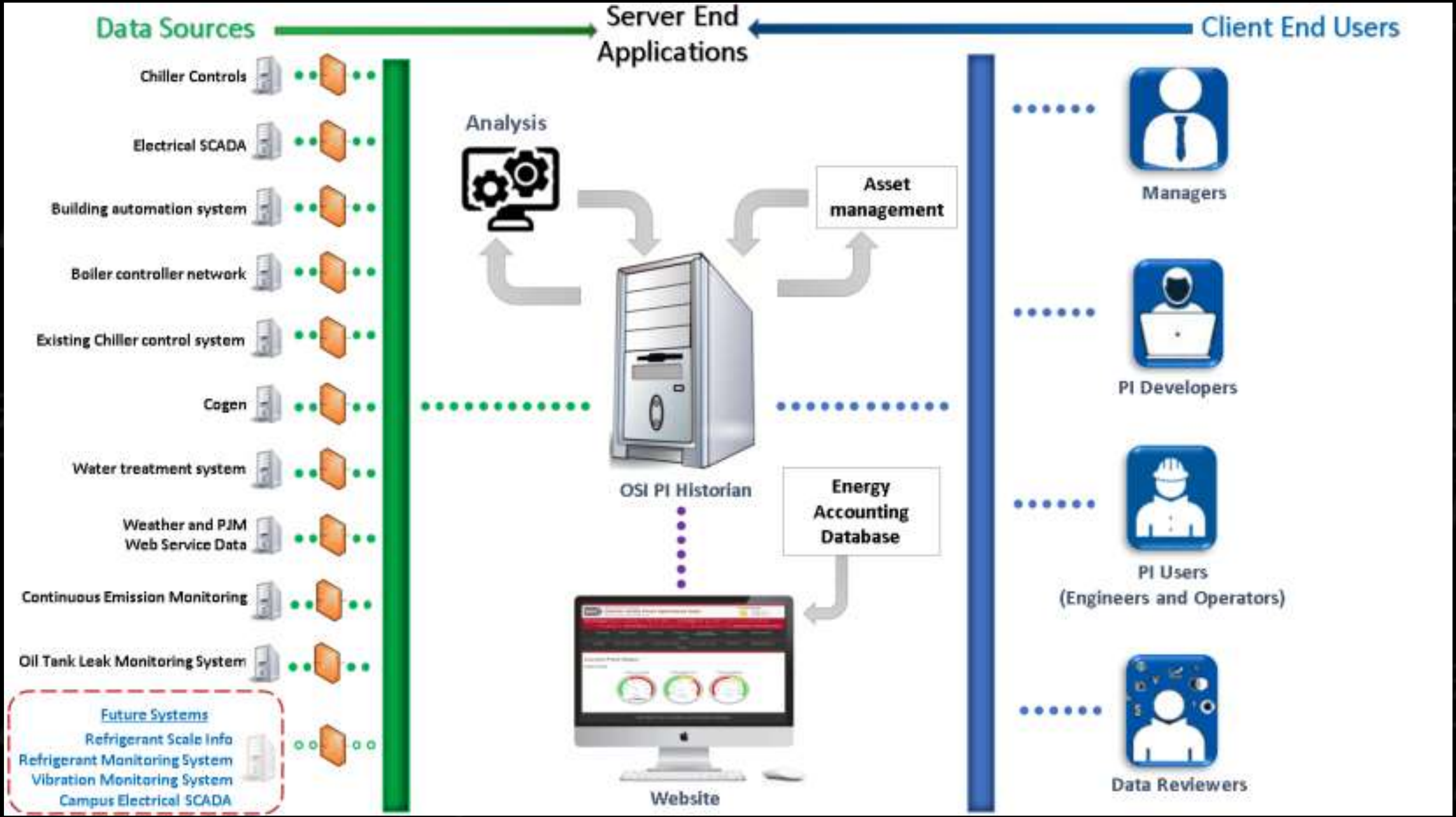


Enterprise-level Cross Platform Data Integration

Collection, Communication Layers

Storage, Analysis Layers

Presentation Layer



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Web-based Executive Level Summaries and Reporting

Executive daily performance and operation data accessible with 1 click:

(Not the actual data)

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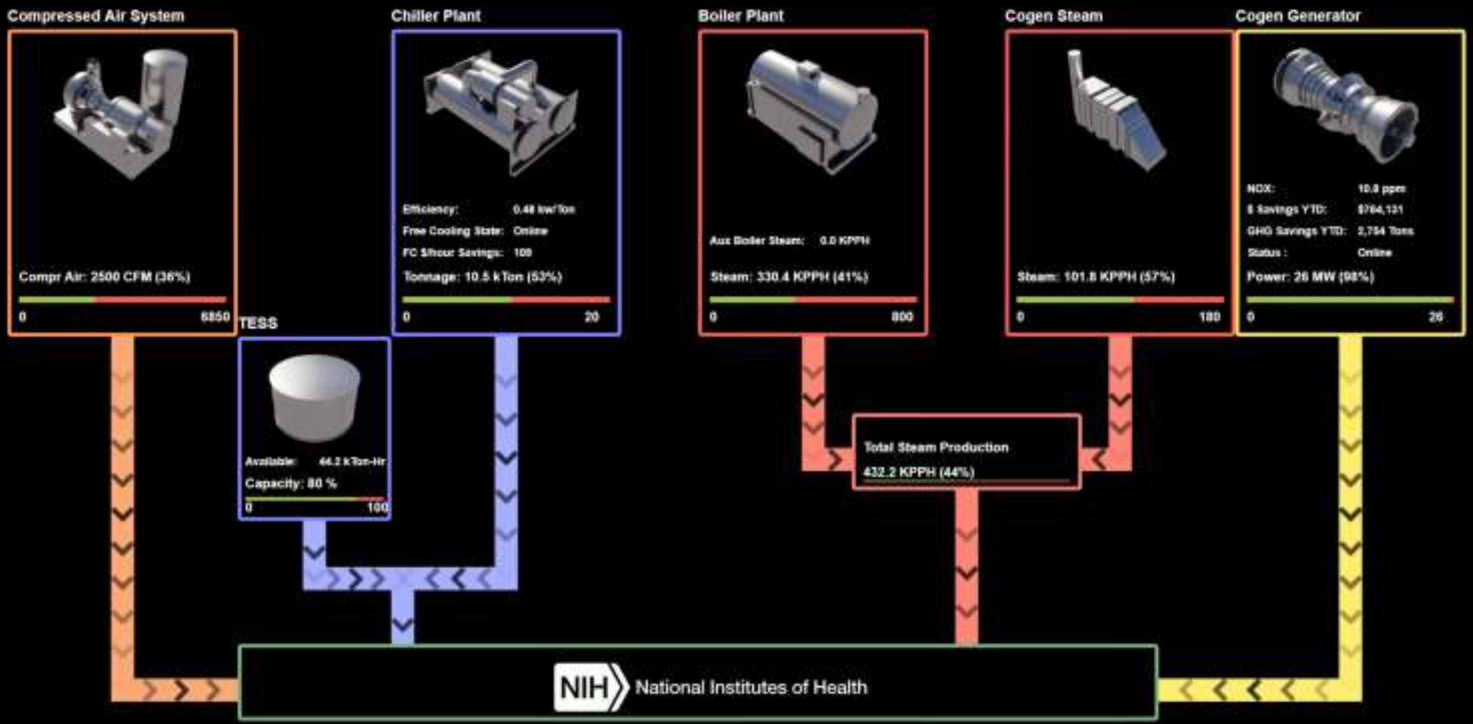
Dynamic CUP Dashboard



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Data Platform Powering the CUP Control Room

The real-time, actionable data drives operations from reactive to proactive.

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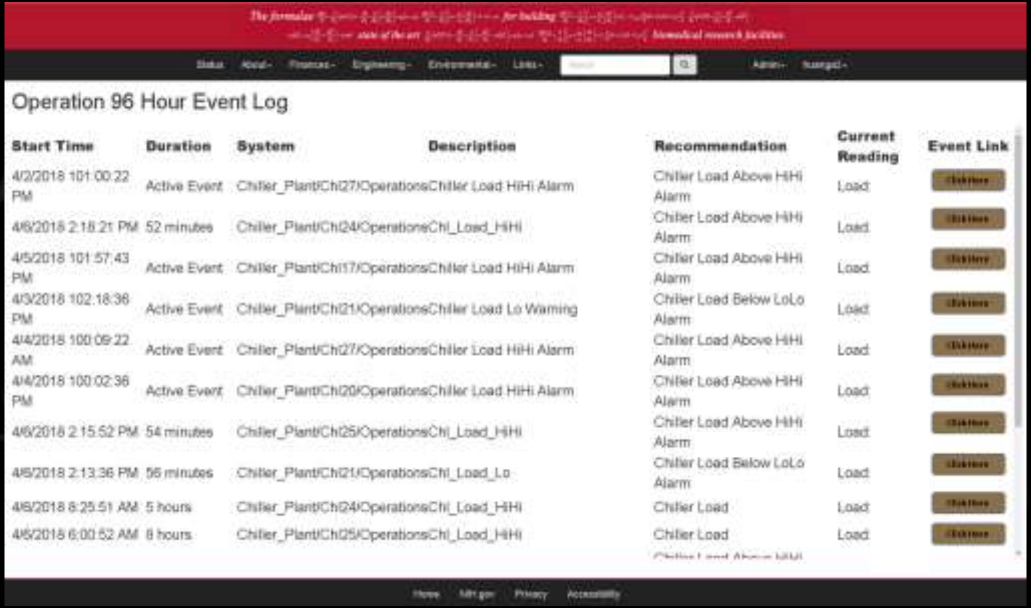
Actionable Operational Intelligence & Fault Detection

Data Platform provides operators actionable intelligence, in-time RCA, and helps review operators' performance

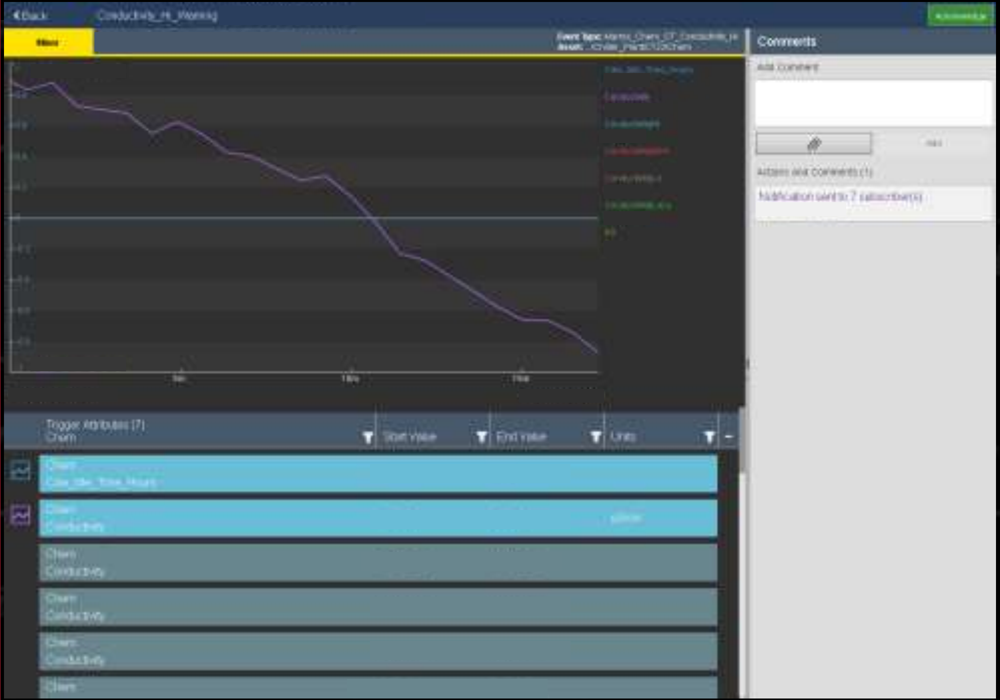


Operation 96 Hour Event Log

Start Time	Duration	System	Description	Recommendation	Current Reading	Event Link
4/2/2018 101:00:22 PM	Active Event	Chiller_Plant/Ch27/Operations	Chiller Load HiHi Alarm	Chiller Load Above HiHi Alarm	Load	Click Here
4/6/2018 2:18:21 PM	52 minutes	Chiller_Plant/Ch24/Operations	Chl_Load_HiHi	Chiller Load Above HiHi Alarm	Load	Click Here
4/5/2018 101:57:43 PM	Active Event	Chiller_Plant/Ch17/Operations	Chiller Load HiHi Alarm	Chiller Load Above HiHi Alarm	Load	Click Here
4/3/2018 102:18:36 PM	Active Event	Chiller_Plant/Ch21/Operations	Chiller Load Lo Warning	Chiller Load Below LoLo Alarm	Load	Click Here
4/4/2018 100:09:22 AM	Active Event	Chiller_Plant/Ch27/Operations	Chiller Load HiHi Alarm	Chiller Load Above HiHi Alarm	Load	Click Here
4/4/2018 100:02:36 PM	Active Event	Chiller_Plant/Ch20/Operations	Chiller Load HiHi Alarm	Chiller Load Above HiHi Alarm	Load	Click Here
4/6/2018 2:15:52 PM	54 minutes	Chiller_Plant/Ch25/Operations	Chl_Load_HiHi	Chiller Load Above HiHi Alarm	Load	Click Here
4/6/2018 2:13:36 PM	56 minutes	Chiller_Plant/Ch21/Operations	Chl_Load_Lo	Chiller Load Below LoLo Alarm	Load	Click Here
4/6/2018 8:25:51 AM	5 hours	Chiller_Plant/Ch24/Operations	Chl_Load_HiHi	Chiller Load	Load	Click Here
4/6/2018 6:00:52 AM	8 hours	Chiller_Plant/Ch25/Operations	Chl_Load_HiHi	Chiller Load	Load	Click Here

(Not the actual data)

Alarm Notification and Mobility



(Not the actual data)

Digitization Plant Operations - Round Data Entry Website

Water Chemistry Data Entry

Boiler | RO | MB | TESS/WS

Select Date

Select Hour ▾

10:00

City Water

Conductivity	(µS/cm)		200 - 600

PI Path: \\ORF-COGENAF\Database1\Chemical_Treatment\Boiler_Plant\City\Operator_Rounds|Conductivity

User	Submitted at	Value	Value timestamp
NIH\johnba	1/17/2019 10:55:19 AM	123	1/17/2019 10:55:19 AM
NIH\johnba	1/18/2019 10:25:19 AM	234	1/18/2019 10:25:19 AM
NIH\johnba	1/19/2019 10:59:40 AM	345	1/19/2019 10:59:40 AM
NIH\johnba	1/20/2019 11:08:41 AM	456	1/20/2019 11:08:41 AM
NIH\johnba	1/21/2019 11:05:29 AM	567	1/21/2019 11:05:29 AM
NIH\gomesaj	1/22/2019 12:00:41 PM	678	1/22/2019 12:00:41 PM
NIH\gomesaj	1/23/2019 10:31:42 AM	789	1/23/2019 10:31:42 AM

Hardness	(ppm)		-
Total Alkalinity	(ppm)		-

Reset Entry Fields

Submit

(Not the actual data)

Risk Management - Weekly Boiler Plant Chemical Dashboard

Boiler Round Data

Boiler Feed Water Round

Description	Value	Units	% compliance
Conductivity Daily Rounds		uS/cm	
pH Daily Rounds			100
O2 Concentration Daily Rounds		ppb	100
Hardness Daily Rounds		ppm	90

Steam Condensate Return Round

Description	Value	Units	% compliance
CRC Amine Daily Round		ppm	

Soft Water Round

Description	Value	Units	% compliance
Hardness Daily Rounds		ppm	100

EB Round

Description	Value	Units	% compliance
Feed ORP Round Data		mV	
Inlet Water Conductivity Round Data		uS/cm	
Outlet Conductivity Round Data		uS/cm	90
Permeate ORP Round Data		mV	
RO Filter Pressure Drop		psi	

RO 1 Round

Description	Value	Units	% compliance
Inlet Hardness Daily Rounds			90
Inlet ORP Daily Rounds		mV	98
RO filter pressure drop			
Outlet Conductivity Daily Rounds		uS/cm	95
Outlet pH Daily Rounds			100
Inlet pH Daily Rounds			90

RO 2 Round

Description	Value	Units	% compliance
Inlet Hardness Daily Round			100
Outlet ORP Daily Rounds		mV	
RO filter pressure drop			
Outlet Conductivity Daily Rounds		uS/cm	96
Outlet pH Daily Rounds			100
Inlet pH Daily Rounds			92

Boiler 1-5 Conductivity Live

Description	uS/cm	% compliance
Boiler 1 Conductivity		100
Boiler 2 Conductivity		100
Boiler 3 Conductivity		100
Boiler 4 Conductivity		100
Boiler 5 Conductivity		100

Boiler 1 Rounds

Description	Ppm	% compliance
Palk Daily Rounds		98
Polymer Daily Rounds		97
Sulfite Daily Rounds		91

Boiler 2 Rounds

Description	PPM	% compliance
Palk Daily Rounds		88
Polymer Daily Rounds		97
Sulfite Daily Rounds		95

Boiler 3 Rounds

Description	Ppm	% compliance
Palk Daily Rounds		90
Polymer Daily Rounds		100
Sulfite Daily Rounds		68

Boiler 4 Rounds

Description	Ppm	% compliance
Palk Daily Rounds	350	100
Polymer Daily Rounds	418	100
Sulfite Daily Rounds	180	97

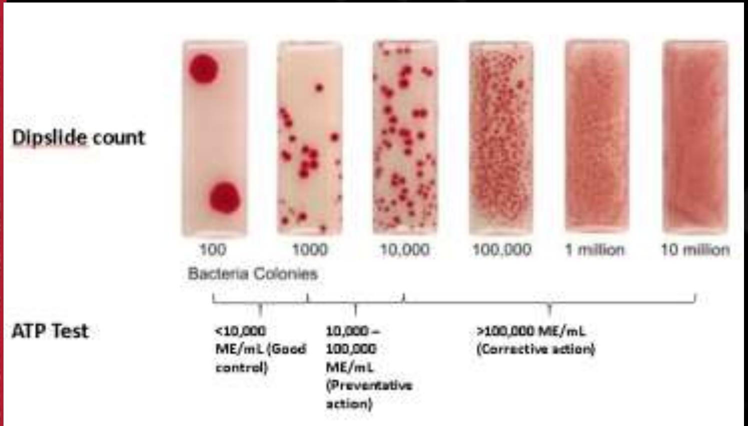
Boiler 5 Rounds

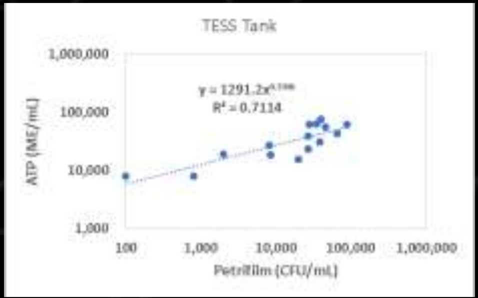
Description	Ppm	% compliance
Palk Daily Rounds		89
Polymer Daily Rounds		95
Sulfite Daily Rounds		97

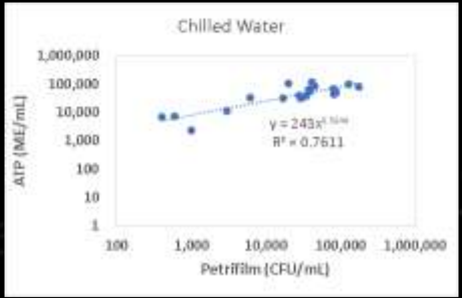
(Not the actual data)

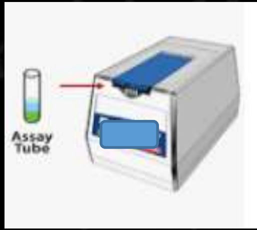
Ongoing Project - Rapid ATP-2G Detection Technology

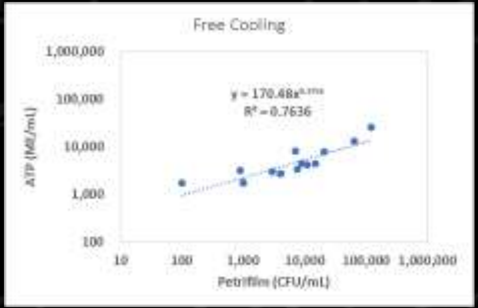
ATP, DipSlides, Petrifilm correlations

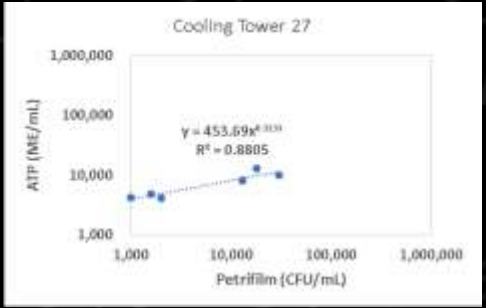












Digitization Plant Operations - Operator Shift Turn Over Website

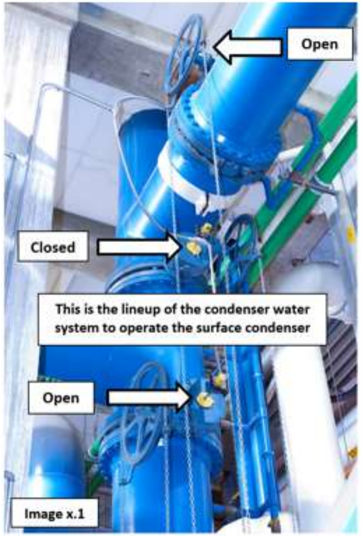
Asset status, work orders closed and submitted, alarms, misc. events, live log, message to the next shift

Digitization Plant Operations – Steam Turbine Readiness Checklist website

Steam Turbine Start up Preliminary Checklist

Chiller 22/ 23

Operator		Ensure that the three condenser and surface condenser isolation valves are **properly lined up** The surface condenser water inlet valve (SCIV-22) and the surface condenser outlet valve (SCOV-22) should be **Open,** and the condenser outlet valve (COV-22) from the chiller condenser should be **Closed.**
Operator		Ensure that the chiller and condenser barrels have been properly vented.
Operator		Ensure that the emergency stop button is **pulled out.**

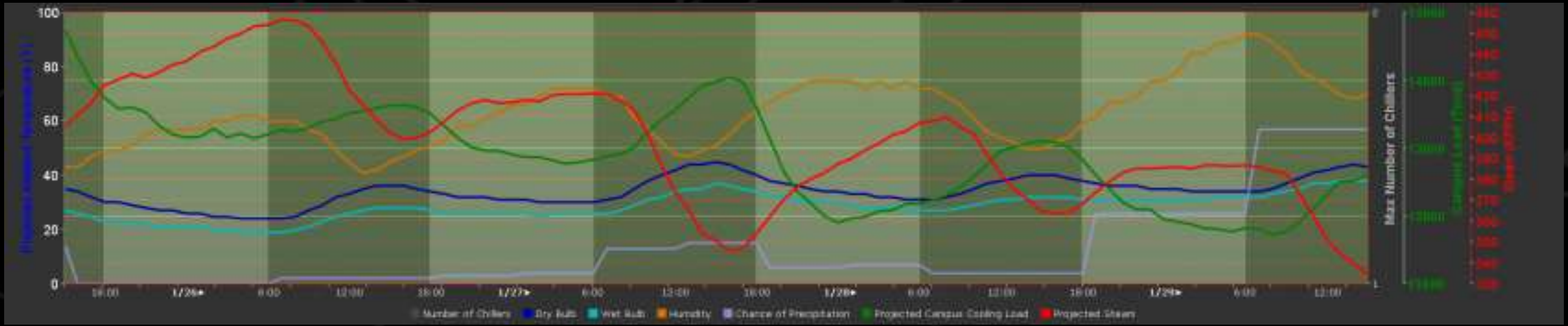


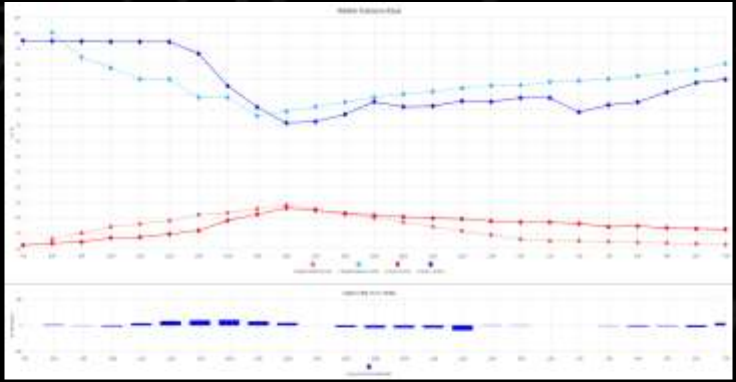
CT roof level | Chiller 22/ 23 | Chiller MCC | Surface condenser

Machine Leaning / Statistical Modeling Methods

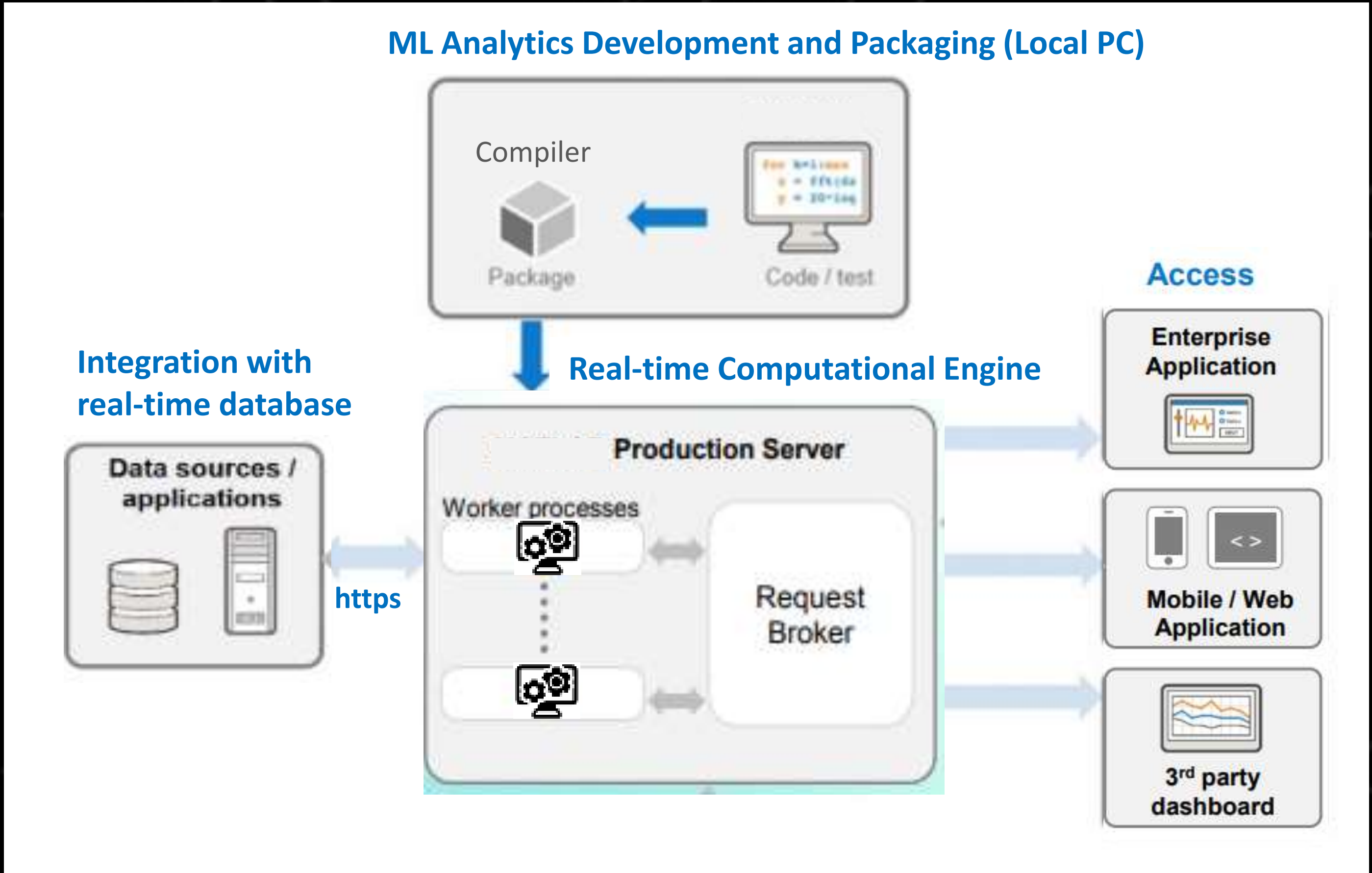
	Supervised Learning	*Unsupervised Learning*
Discrete	Classification or Categorization	Clustering
Continuous	Regression	Dimensionality Reduction

ANN based Load Forecaster and Online Error Analysis



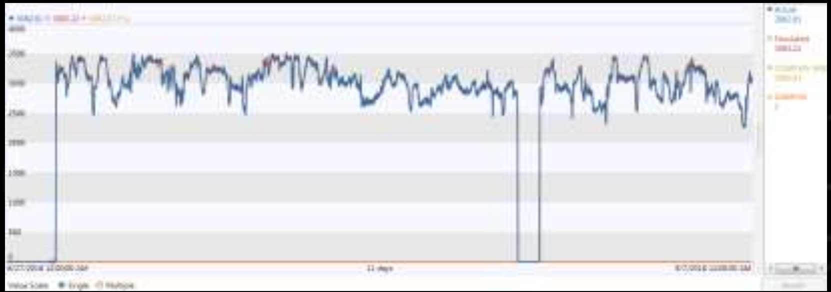


Streaming Machine Learning Calculations Architect

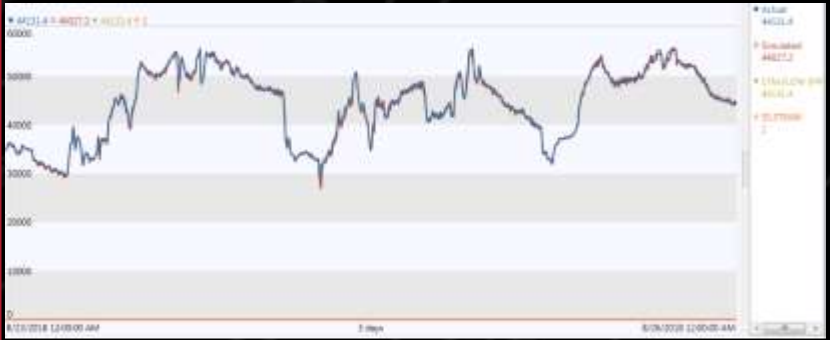


Real-Time Machine Learning Integration: Simulated Compressor Performance

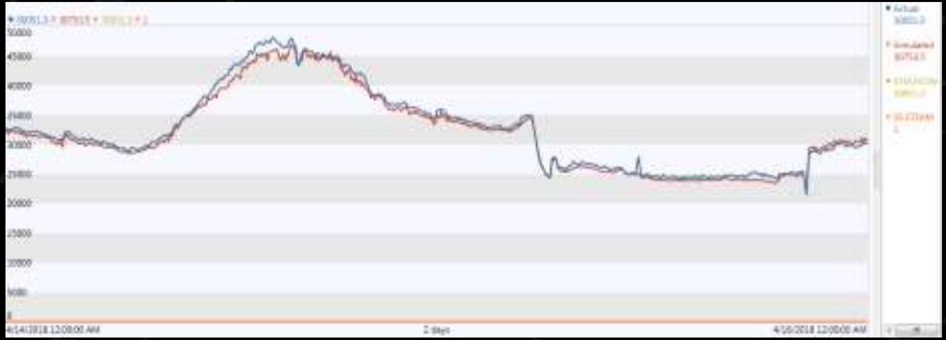
Compressor 26



Compressor 27



Steam-driven Compressor 23



Steam-driven Compressor 22

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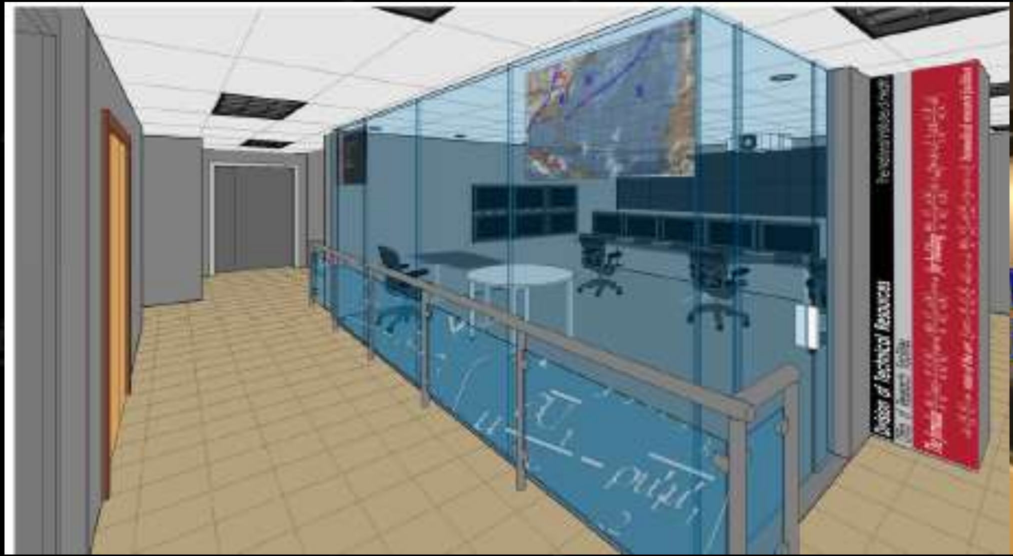
Ongoing Project – Operator Simulator Project

Operator training on normal and emergency scenarios, situation playback, evaluate innovative control strategy and optimize the process



Chiller Plant Optimization

Objective function: Minimize (the total equivalent cost in next 48 hrs)

The individual component models are from machine learning models

The Constraints:

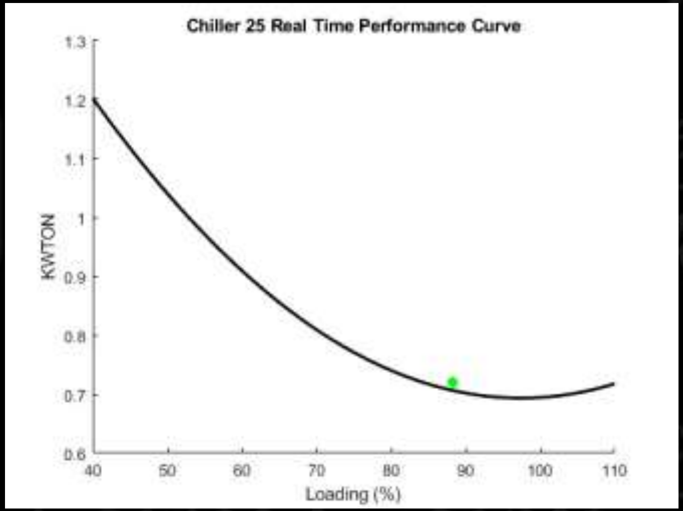
- Chiller run time and availability
- Electrical feeder load balance
- Limits of the individual chiller /free cooling capacity, flow, temp, etc.
- TES tank status and capacity
- Load Forecasting and Energy Balance
- Future PJM Electricity Price

The Decision Variables:

- The chiller condenser evaporator flow, temp
- The load distribution among the chillers
- Free cooling flow, number of heat exchangers
- TES charge / discharge dispatch decision and flow

Asset Availability Website

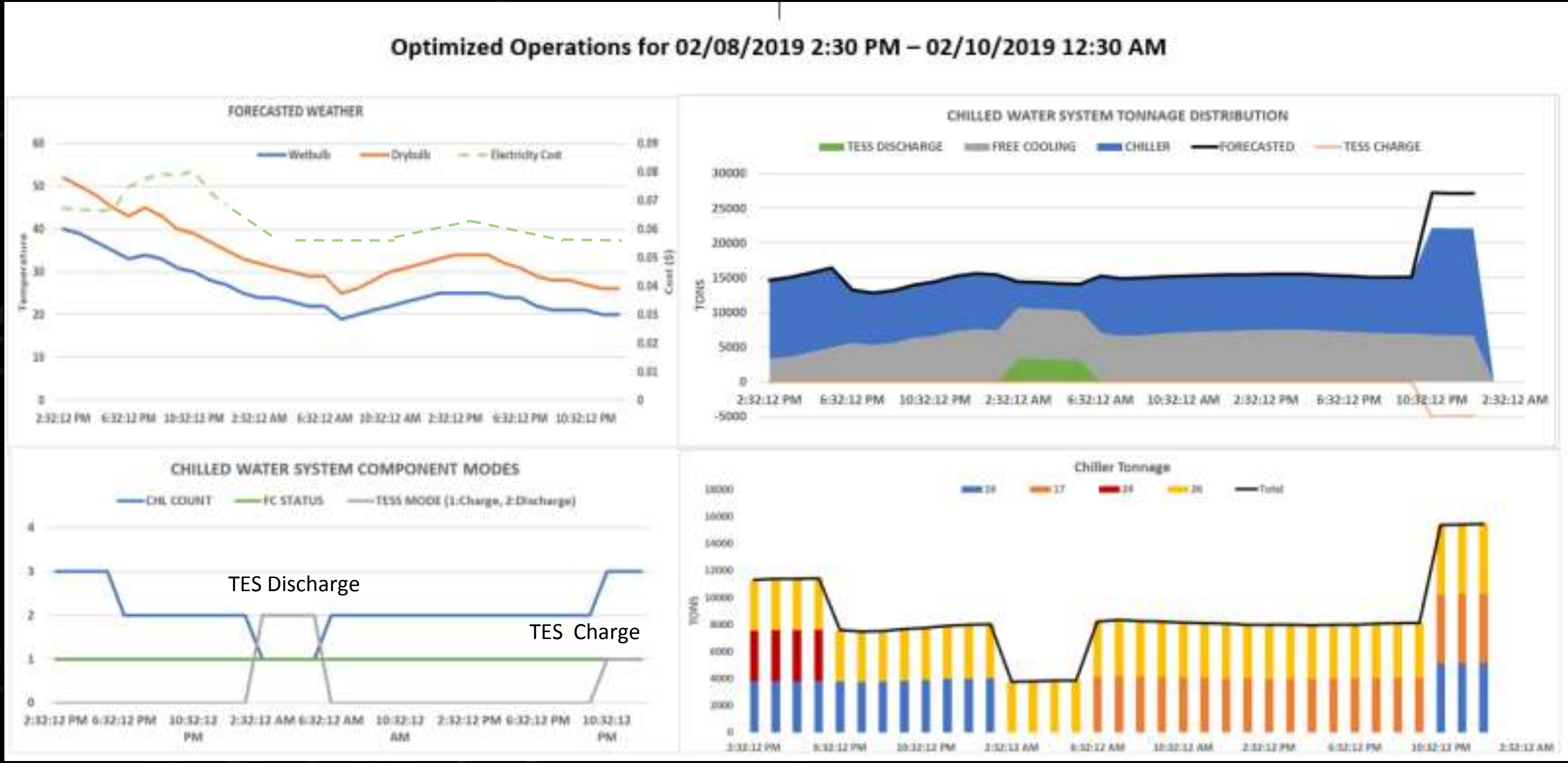
Optimization Animation



Optimization Results and Recommendations

Typical Suggestions:

Run minimum number of chillers, shift more load to free cooling, the more efficient chillers or the steam turbine chiller, run more cooling tower cells to reduce the tower return temp, or increase the chilled water supply temp.



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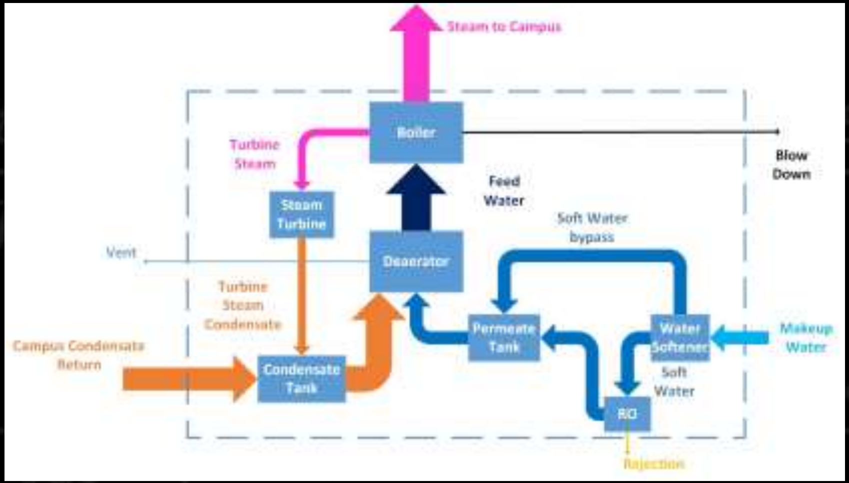
Data Quality Life Cycle Management

Data Generation

Calibrate and maintain the sensors
Fix the data / interface communication errors
Online statistic scan
Identify the incorrect and missing data
Clean and smooth the data
Error propagation and metrological standards

Data Utilization



Calculation Handbook and Change Management SOP
Daily / Monthly Dashboard Review SOP
Machine baseline and health check
Energy / mass/ cost balance and cross disciplinary check
Auto Fault Detection, text message & emails notifications

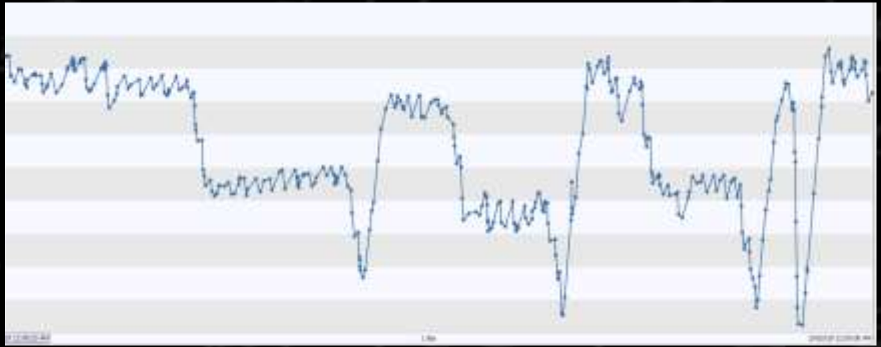
SQC Signal-Noise Based Data Compression and Clean Process

Goal:

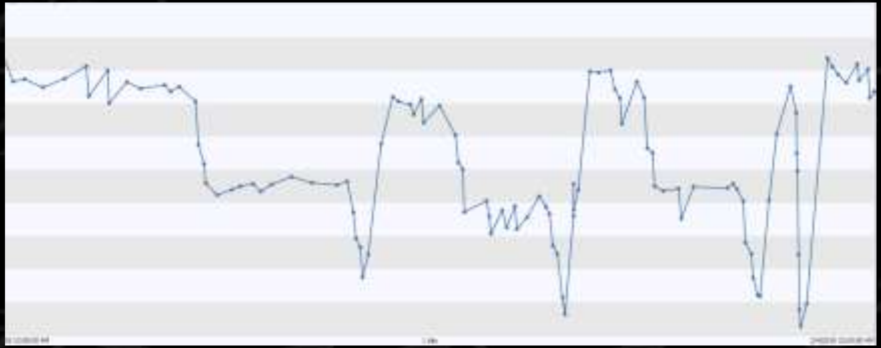
- Obtain reliable post-processed data
- Actionable plans based on more reliable and trusted data without too much need for post processing.

Results:

- Saved hours of time spent on post processing the noise.
- Less space used on server
- Less load on server
- Cost savings for plant operation due to better data for forecasting and optimization modeling.



Before

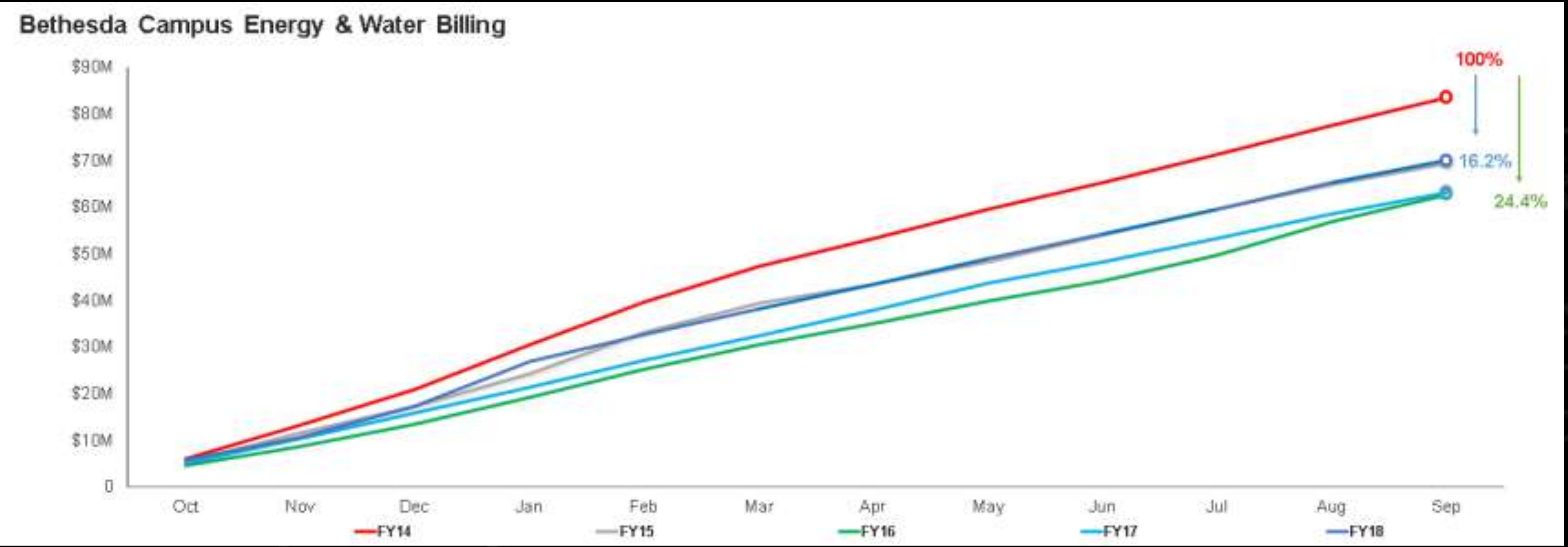


After

Real-time Data Quality Dashboard

Tangible Results – Financial

Millions of dollars saved despite increased utility costs & demand!



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Thank You

Many thanks to NIH Office of Research Facilities Director Mr. Dan Wheeland, Division of Technical Resources (DTR) Director Dr. Farhad Memarzadeh, Deputy Director Mrs. Alamelu Ramesh, and colleagues in DTR team to make all of these happen!

Contact Information

Don Guan Ph.D. P.E.
don.guan@nih.gov
Chief, Utilities Engineering Branch
Division of Technical Resources

Alex Huang
alex.huang@nih.gov
Mechanical Engineer
Utilities Engineering Branch
Division of Technical Resources

Kayvan Torkashvan
kayvan.torkashvan@nih.gov
General Engineer
Utilities Engineering Branch
Division of Technical Resources

Data Generation

Energy Balance

$$Energy\ In = Energy\ Out$$

$$Q_{In} + W_{in} = Q_{out}$$

$$Tons_{Evap} + kW = Tons_{Cond}$$

$$Percent = \frac{Tons_{Evap} * Conversion + kW}{Tons_{Cond} * Conversion} * 100$$

Error Propagation

$$kW = \sqrt{3} * V * I * PF$$

$$\frac{\partial kW}{\partial V} = \sqrt{3} * I * PF$$

$$\frac{\partial kW}{\partial I} = \sqrt{3} * V * PF$$

$$\frac{\partial kW}{\partial PF} = \sqrt{3} * V * I$$

$$W = \dot{m}(h_i - h_e) * Conversion$$

$$h_i = enthalpy\ at\ Steam\ Turbine\ Inlet\ at\ Saturation$$

$$h_e = enthalpy\ at\ Surface\ Condenser\ Vacuum\ Pressure$$

$$s_{i,Compressor} = \sqrt{\left(\left(\frac{\partial W}{\partial m}\right)^2 s_m^2 + \left(\frac{\partial W}{\partial h_i}\right)^2 s_{h_i}^2 + \left(\frac{\partial W}{\partial h_e}\right)^2 s_{h_e}^2\right) * Conversion^2}$$

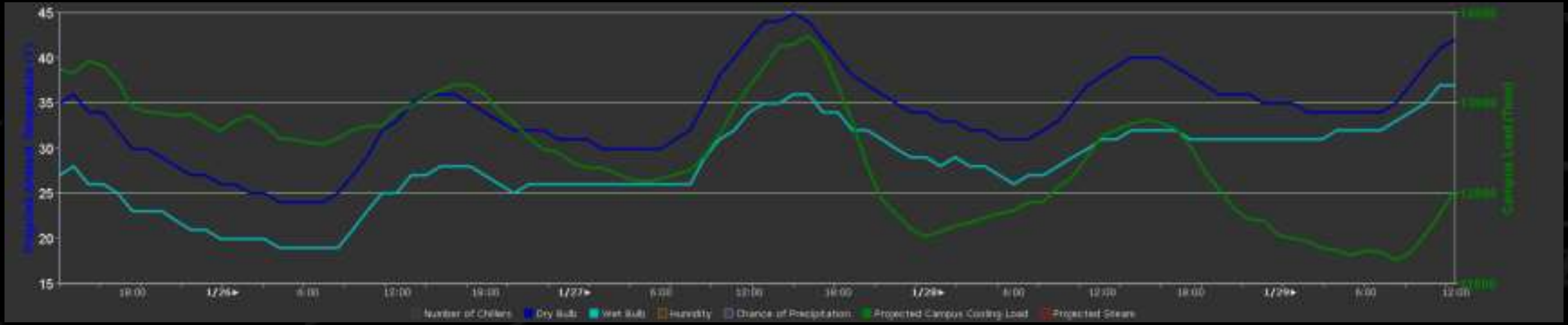
$$s_{i,Cdw\ Pump} = \sqrt{\left(\frac{\partial kW}{\partial V}\right)^2 s_V^2 + \left(\frac{\partial kW}{\partial I}\right)^2 s_I^2 + \left(\frac{\partial kW}{\partial PF}\right)^2 s_{PF}^2}$$

$$s_{i,Chw\ Pump} = \sqrt{\left(\frac{\partial kW}{\partial V}\right)^2 s_V^2 + \left(\frac{\partial kW}{\partial I}\right)^2 s_I^2 + \left(\frac{\partial kW}{\partial PF}\right)^2 s_{PF}^2}$$

$$s_{i,CT\ Pump} = \sqrt{\left(\frac{\partial kW}{\partial V}\right)^2 s_V^2 + \left(\frac{\partial kW}{\partial I}\right)^2 s_I^2 + \left(\frac{\partial kW}{\partial PF}\right)^2 s_{PF}^2}$$

$$s_{i,kW} = \sqrt{s_{Compressor}^2 + s_{Chw\ Pump}^2 + s_{Cdw\ Pump}^2 + s_{CT}^2}$$

Machine Learning Models Learning



- Model learned cooling load vs. ambient lead/lag effect
- Learned using data with no explicit context
- Took several years worth of data to recognize pattern
- Data provided insight on system dynamics with respect to weekend/weekday, time lag between ambient heat and cooling load, increase in demand for steam on weekdays around 8am and 5pm