# UC Davis Chilled Water, Thermal Storage, and Building Integrated Optimization Project

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CampusEnergy2020
THE POWER TO CHANGE
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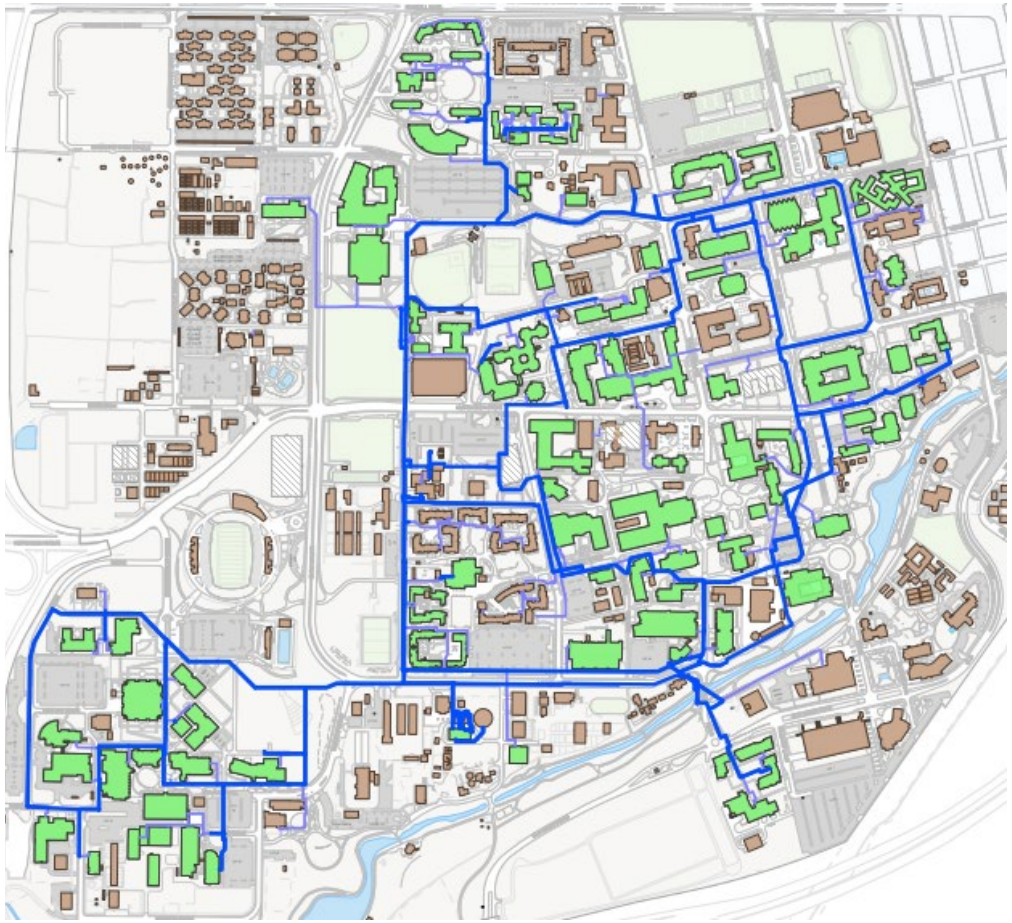
# UC Davis Campus



- Nearly 100 buildings on district cooling
- Two chiller plants
- Daily population 50,000

# Chiller Plants

**Central Heating & Cooling Plant (CHCP)**

- 10,000 tons
- 4 centrifugal chillers
- Primary/Secondary CHW pumps
- 5 cooling tower cells


**Thermal Energy Storage Plant (TES)**

- 8,000 tons
- 4 centrifugal chillers
- Primary/Secondary CHW pumps
- 12 cooling tower cells
- 5 Mgal TES tank (40k to 50k ton-hr)

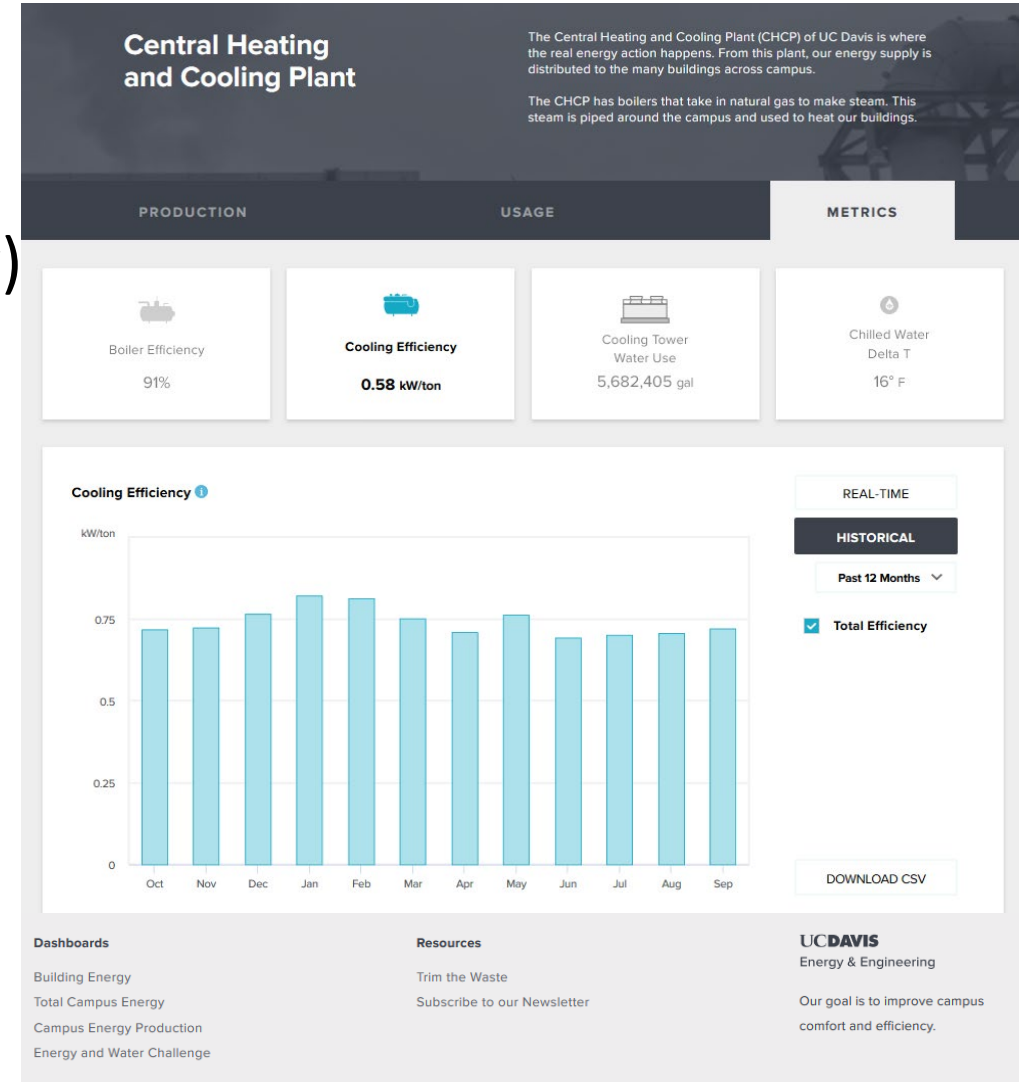
**40 million ton-hr/yr**
**12°F average ΔT**
**0.70 kW/ton (plant)**
**$0.07/kWh (average)**
**$2M annual cost**

# Pre-project Status

- Chiller plants
  - Operator shift-based TES dispatch
  - Fixed condenser water supply temperature
  - Fixed chilled water supply temperature
  - Insufficient chiller performance monitoring
- Buildings
  - Inconsistent design and use of bypass and bridge valves
  - Contribute to low system ΔT
  - Nonoptimal/nonexistent air side P and T resets

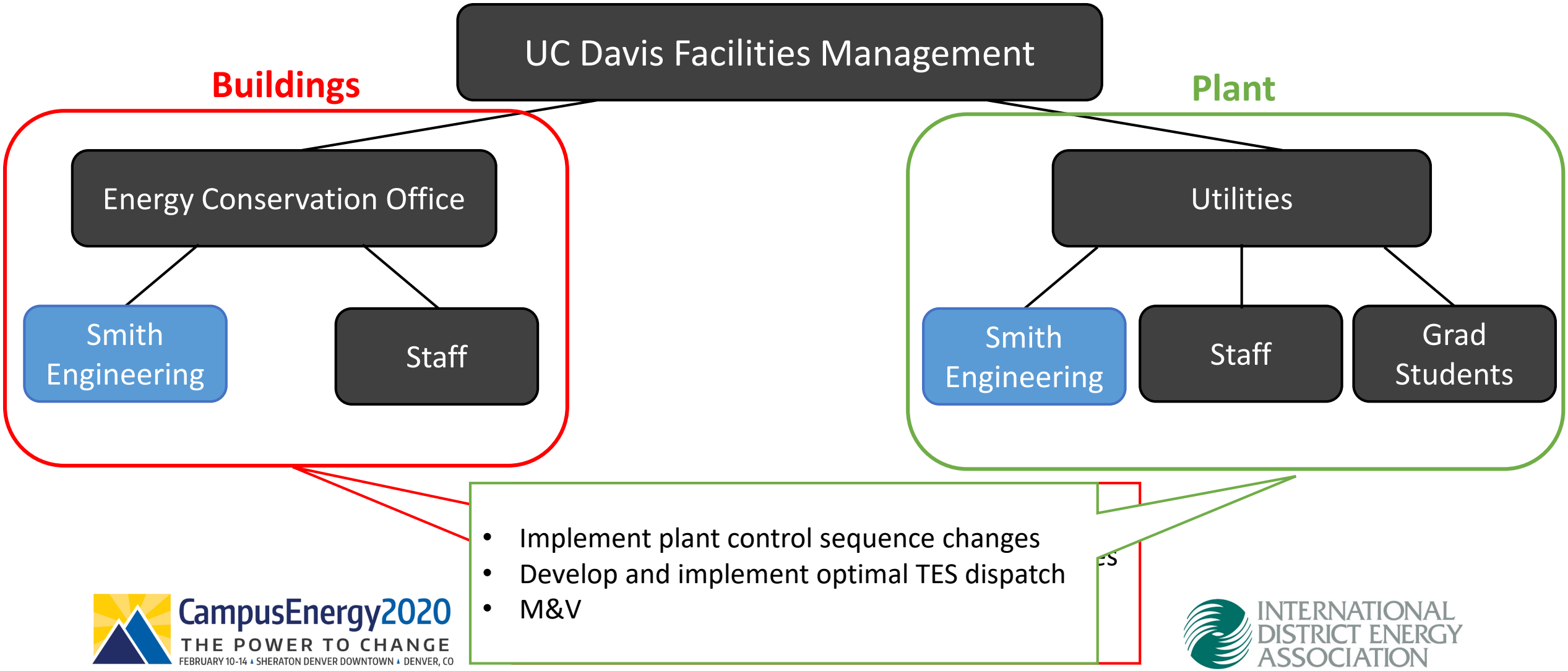
# Project Goals

- System-wide approach
  - Improve the buildings (pilot and deploy)
  - Improve the plant
- Fast implementation
  - Steam-to-HW will cause changes
  - Get most savings with minimal effort
- Capital-free (or low capital)
- Collaborative partner
  - Implement and teach
  - Leverage in-house knowledge
- Fee limited by savings




ceed.ucdavis.edu/chcp/

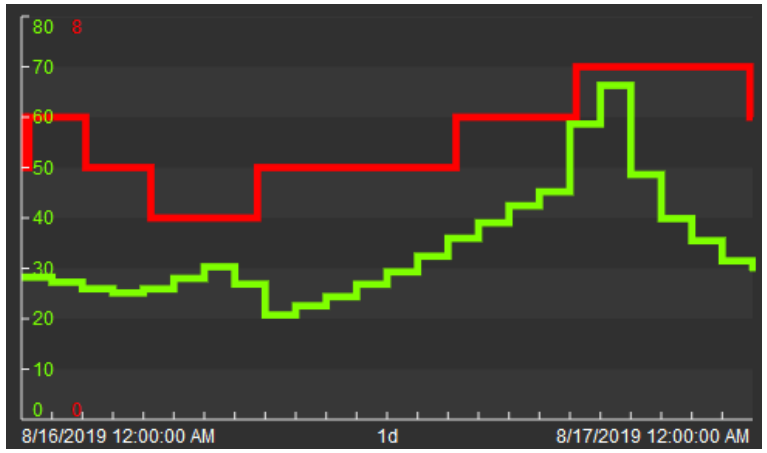
# Project Organization

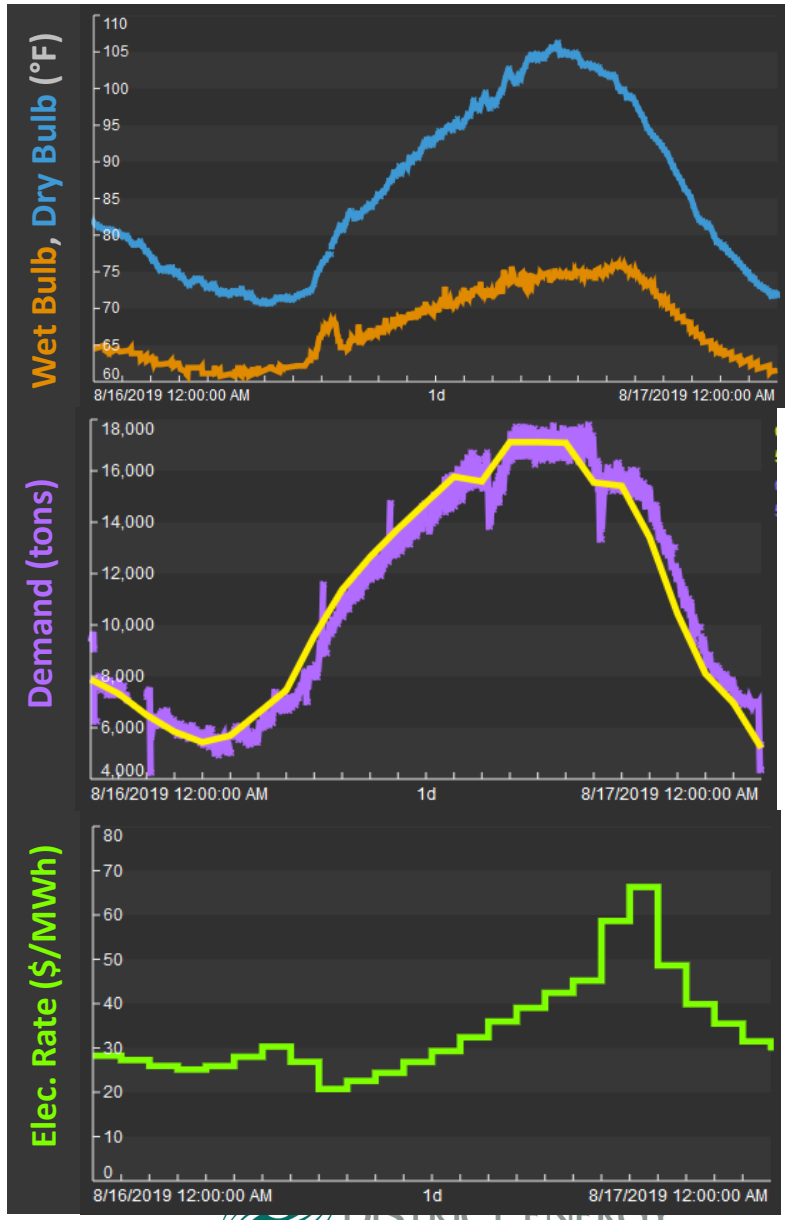


# Opportunity: Rate

- Historical method of operation:
  - Night: Complete charging the tank
  - Day: Ride it out, use the tank
  - Swing: Turn on chillers, begin charging tank

**Chillers Running**



# Opportunity: Rate, continued…

**Impacts of Efficiency and Rate**

| | kW/Ton | $/MWh |
|---|---|---|
| Max | 0.90 | $70 |
| Min | 0.60 | $20 |
| Max/Min | 1.5 | 3.5 |

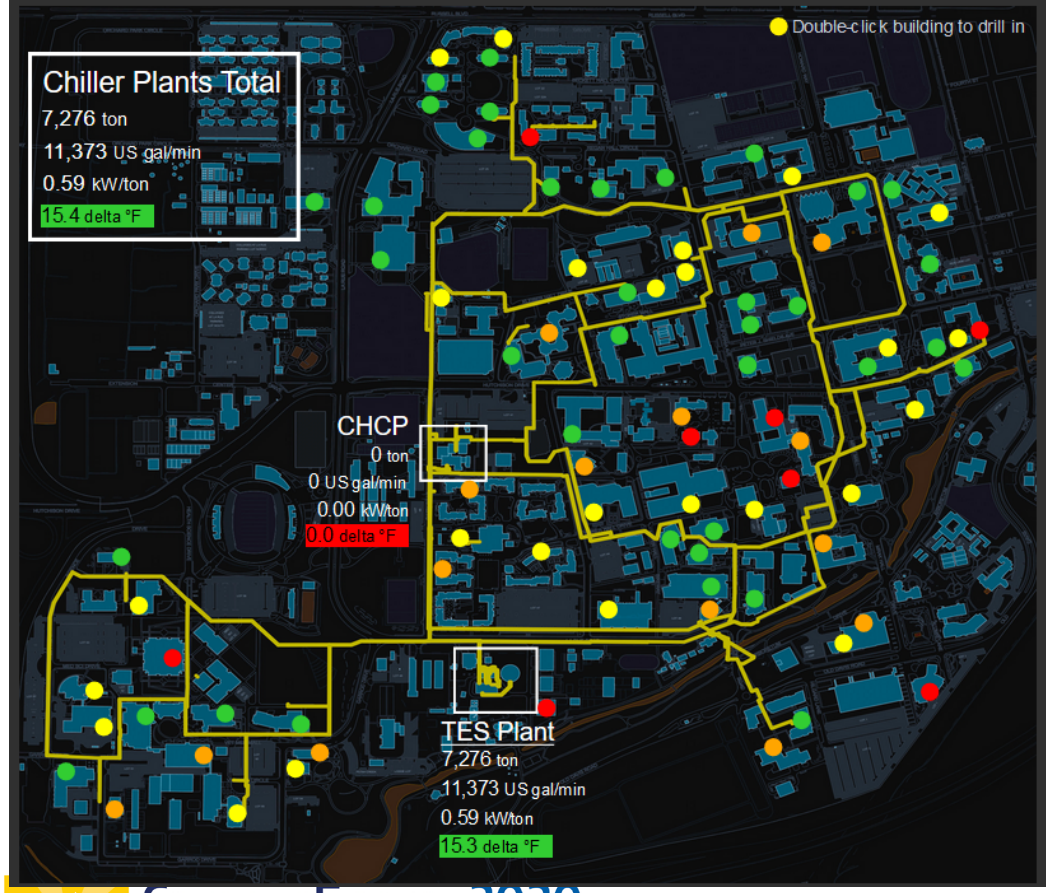
*$ = 10,000 Ton * 0.90 kW/Ton * $0.02 = $180*

*$ = 10,000 Ton * 0.60 kW/Ton * $0.07 = $420*

# Opportunity: ΔT

## Chilled Water Utilization

10/18/2019 2:39:30 PM




| Chilled Water Utilization | Heat (tons) | Heat (% of Total) | Flow (gpm) | Flow (% of Total) |
|---|---|---|---|---|
| ΔT < 5°F | 10 | 0 % | 420 | 4 % |
| ΔT = 5 - 10°F | 815 | 11 % | 2,548 | 22 % |
| ΔT = 10 - 15°F | 1,318 | 18 % | 2,520 | 22 % |
| ΔT > 15°F | 2,752 | 38 % | 2,911 | 26 % |
| ΔT unknown | 2,287 | 29 % | 2,809 | 22 % |

### Building Performance

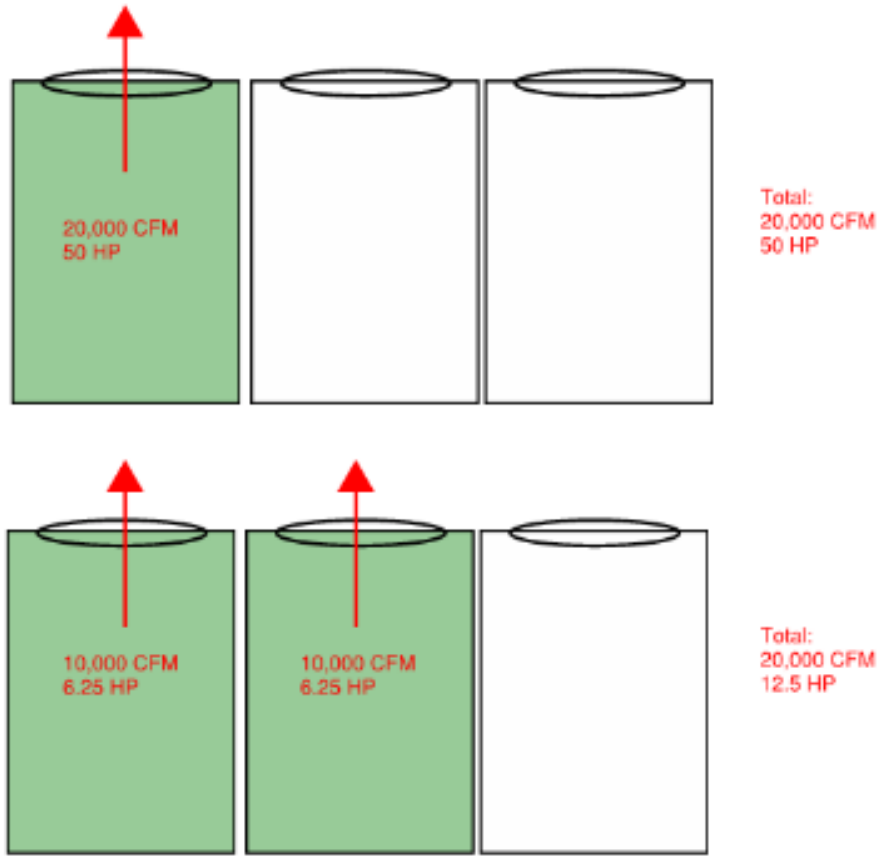
Double-click building name to drill in

| | | | |
|---|---|---|---|
| Academic_Surge_Building | 24.4 delta °F | 97 ton | 93 US gal/min |
| Activities_and_Recreation_Center | 23.7 delta °F | 232 ton | 234 US gal/min |
| Ann_E._Pitzer_Center | 16.7 delta °F | 8 ton | 12 US gal/min |
| Art_Music_&_Wright | 10.4 delta °F | 2 ton | 4 US gal/min |
| Asmundson_Hall | 14.3 delta °F | 32 ton | 53 US gal/min |
| Bainer_Hall | 12.9 delta °F | 16 ton | 30 US gal/min |
| Briggs_Hall | 9.8 delta °F | 88 ton | 217 US gal/min |
| California_Hall | 11.1 delta °F | 3 ton | 7 US gal/min |
| Center_for_Companion_Animal_Health | 11.7 delta °F | 88 ton | 180 US gal/min |
| Central_Cage_Wash | 17.0 delta °F | 22 ton | 30 US gal/min |
| CFA_Administration_Building | 10.1 delta °F | 11 ton | 27 US gal/min |
| CFA_Mondavi | 7.7 delta °F | 131 ton | 403 US gal/min |
| Chemistry | 3.2 delta °F | 0 ton | 0 US gal/min |
| Chemistry_Annex | 5.4 delta °F | 36 ton | 161 US gal/min |
| Cole_B | 2.9 delta °F | 0 ton | 0 US gal/min |
| Cruess_Hall | 22.0 delta °F | 20 ton | 22 US gal/min |
| Dutton_Hall | 33.1 delta °F | 41 ton | 25 US gal/min |
| Earth_and_Physical_Sciences_Building | 17.7 delta °F | 131 ton | 180 US gal/min |
| Genome_&_Biomedical_Sciences | 11.5 delta °F | 89 ton | 186 US gal/min |

# Plant Optimization: Training

- Learn from operators
- Builds Trust
- Reduces Fear
- Opens Lines of communication
- Operators become part of the team

# Plant Optimization: Tower Staging




Fan Affinity Law

Fan Power varies with x^3 of flow

50 HP at ½ speed = 6.25 HP

# Plant Optimization: CWST

**CDHF Efficiency Map (kW/Ton)**

**Chiller Percent Load (Load/Design Load)**

| ECWT (F) | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92 | | | | | | | | | | | | | | | | | | | | | | 0.55 | | 0.53 | | | 0.47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 90 | | | | | | | | | | | | | | | | | | | | | | | | | | 0.48 | | | | | | | | | | | | | | 0.51 | 0.51 | | 0.49 | | | | | | | | | | | | | | | |
| 88 | | | | | | | | | | | | | | | | | | | | | | | | | | 0.47 | 0.47 | 0.46 | | 0.64 | | 0.49 | | 0.44 | | | 0.51 | 0.51 | 0.5 | 0.5 | 0.49 | 0.49 | 0.48 | 0.48 | | 0.46 | | 0.44 | | | | | | | | |
| 86 | | | | | | | | | | | | | | | | | | | | 0.58 | | 0.55 | | 0.58 | 0.58 | 0.55 | 0.53 | 0.55 | 0.55 | 0.55 | 0.5 | 0.54 | 0.51 | 0.51 | 0.52 | 0.51 | 0.51 | 0.51 | 0.5 | 0.49 | 0.48 | 0.49 | 0.49 | | 0.44 | | 0.45 | | | | | | | | |
| 84 | | | | | | | | 0.66 | | 0.57 | 0.55 | 0.54 | 0.53 | | | | | | 0.58 | 0.56 | 0.55 | 0.53 | 0.52 | 0.53 | 0.49 | 0.49 | 0.52 | 0.51 | 0.53 | 0.52 | 0.53 | 0.54 | 0.52 | 0.52 | 0.52 | 0.5 | 0.5 | 0.5 | 0.49 | 0.47 | 0.48 | 0.47 | 0.47 | 0.46 | 0.46 | 0.44 | 0.44 | 0.42 | 0.42 | 0.42 | 0.41 | 0.41 | | |
| 82 | | | | | | | | | | 0.57 | 0.57 | 0.53 | 0.54 | 0.52 | 0.56 | 0.54 | 0.53 | 0.6 | 0.58 | 0.5 | 0.57 | 0.53 | 0.5 | 0.49 | 0.53 | 0.47 | 0.5 | 0.51 | 0.51 | 0.53 | 0.54 | 0.53 | 0.53 | 0.52 | 0.51 | 0.49 | 0.48 | 0.47 | 0.47 | 0.46 | 0.46 | 0.45 | 0.46 | 0.44 | 0.44 | 0.44 | 0.43 | 0.42 | 0.41 | 0.41 | 0.42 | 0.4 | | |
| 80 | | 0.85 | | | | | | 0.63 | 0.58 | 0.56 | 0.56 | 0.53 | 0.52 | 0.53 | 0.58 | 0.55 | 0.59 | 0.53 | 0.55 | 0.5 | 0.47 | 0.51 | 0.5 | 0.48 | 0.48 | 0.47 | 0.49 | 0.47 | 0.47 | 0.49 | 0.49 | 0.49 | 0.5 | 0.49 | 0.5 | 0.49 | 0.48 | 0.46 | 0.45 | 0.45 | 0.44 | 0.44 | 0.44 | 0.43 | 0.43 | 0.42 | 0.42 | 0.41 | 0.41 | 0.41 | 0.4 | 0.39 | | |
| 78 | | | | | | | | 0.56 | 0.55 | 0.55 | 0.53 | 0.5 | 0.51 | 0.55 | 0.54 | 0.55 | 0.53 | 0.52 | 0.52 | 0.49 | 0.49 | 0.47 | 0.44 | 0.43 | 0.43 | 0.45 | 0.45 | 0.45 | 0.44 | 0.45 | 0.46 | 0.47 | 0.46 | 0.45 | 0.46 | 0.44 | 0.45 | 0.44 | 0.44 | 0.43 | 0.44 | 0.43 | 0.43 | 0.42 | 0.42 | 0.42 | 0.41 | 0.41 | 0.41 | 0.4 | 0.4 | 0.4 | | |
| 76 | 0.88 | 0.75 | 0.73 | 0.64 | 0.67 | 0.65 | 0.63 | 0.58 | 0.62 | 0.57 | 0.55 | 0.53 | 0.52 | 0.52 | 0.53 | 0.53 | 0.52 | 0.49 | 0.48 | 0.47 | 0.46 | 0.45 | 0.43 | 0.42 | 0.41 | 0.41 | 0.41 | 0.41 | 0.42 | 0.41 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.39 | 0.4 | 0.4 | 0.4 | 0.36 | 0.38 | | 0.37 |
| 74 | 0.84 | 0.85 | 0.69 | 0.71 | 0.67 | 0.58 | 0.66 | 0.64 | 0.63 | 0.59 | 0.56 | 0.52 | 0.5 | 0.49 | 0.49 | 0.57 | 0.48 | 0.48 | 0.48 | 0.46 | 0.45 | 0.43 | 0.42 | 0.41 | 0.4 | 0.4 | 0.4 | 0.4 | 0.38 | 0.39 | 0.4 | 0.4 | 0.39 | 0.4 | 0.39 | 0.38 | 0.38 | 0.4 | 0.39 | 0.39 | 0.39 | 0.41 | 0.4 | 0.4 | 0.39 | 0.41 | 0.4 | 0.39 | 0.38 | 0.41 | | 0.37 | | |
| 72 | | 1.16 | 0.69 | 0.67 | 0.68 | 0.67 | 0.66 | 0.61 | 0.61 | 0.6 | 0.57 | 0.53 | 0.51 | 0.51 | 0.52 | 0.51 | 0.48 | 0.48 | 0.48 | 0.46 | 0.45 | 0.42 | 0.42 | 0.4 | 0.4 | 0.4 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.38 | 0.38 | 0.39 | 0.39 | 0.39 | 0.39 | 0.4 | 0.39 | 0.42 | 0.41 | 0.41 | 0.41 | 0.4 | 0.39 | | 0.41 | | | | | | |
| 70 | | | 0.79 | 0.76 | | 0.63 | 0.58 | | | | 0.66 | 0.61 | | 0.49 | | 0.5 | 0.48 | 0.48 | 0.48 | 0.45 | 0.44 | 0.42 | 0.4 | 0.4 | 0.39 | 0.38 | 0.38 | 0.39 | 0.39 | 0.4 | 0.37 | 0.37 | | 0.41 | 0.4 | 0.38 | 0.4 | 0.39 | | | | 0.39 | | | | | | | | | | | | | |
| 68 | 0.8 | 0.82 | 0.82 | 0.76 | | 0.6 | 0.6 | 0.67 | 0.48 | 0.54 | 0.51 | 0.46 | 0.45 | 0.49 | 0.49 | 0.46 | 0.46 | 0.48 | 0.46 | 0.45 | 0.43 | 0.41 | 0.41 | 0.4 | | 0.38 | 0.4 | 0.38 | 0.37 | 0.37 | 0.37 | 0.38 | | 0.38 | | | | | | | | 0.39 | | | | | | | | | | | | | |
| 66 | | | | | | | | | | | | | | 0.47 | | 0.45 | | 0.43 | 0.41 | 0.43 | 0.4 | 0.42 | | 0.4 | 0.39 | 0.37 | | | | | | | | | | | | | | 0.37 | | | | | | | | | | | | | |
| 64 | | | | | | | | | | | | 0.5 | | 0.51 | 0.5 | 0.45 | 0.48 | 0.45 | 0.47 | 0.44 | 0.41 | 0.41 | | 0.45 | | | | | | | | | | | 0.39 | | | | | | | | | | | | | | | | | | | |
| 62 | | | | | | | | | | | 0.53 | 0.54 | | | | | | 0.44 | 0.46 | 0.46 | | | | 0.37 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | 0.55 | 0.56 | | | 0.49 | 0.47 | 0.48 | 0.47 | | 0.48 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 58 | | | | | | | | | | | | | | 0.52 | 0.57 | 0.45 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 56 | | | | | 0.53 | | | 0.72 | 0.49 | | | 0.56 | | 0.52 | 0.49 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 54 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 52 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

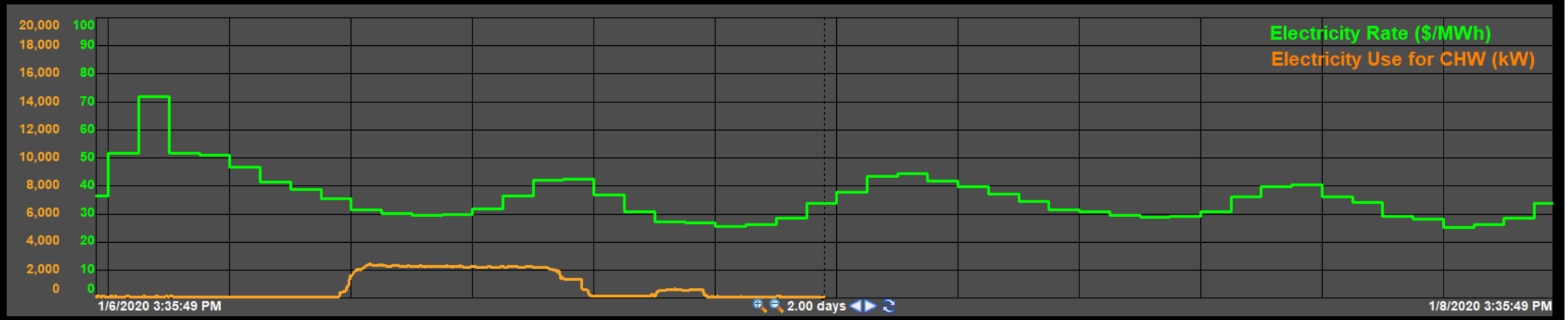
# Plant Optimization: Rate-Driven TES Dispatch

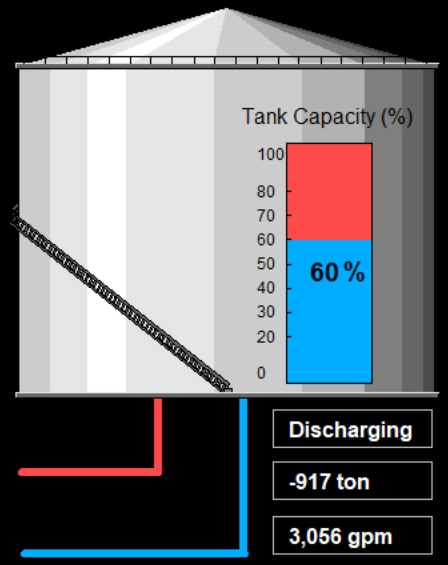
07.Jan.2020 3:35 PM

Zoom to Fit

CHW Map

**UCD Electricity Cost ($/MWh) and Chilled Water Electricity Demand (kW)**



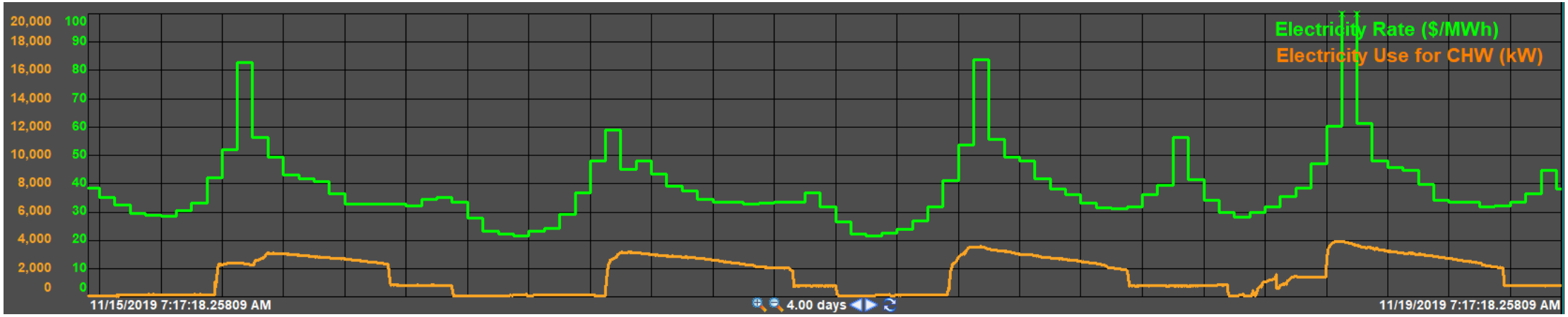




The TES Tank (by itself) could satisfy campus for the next **17 h**

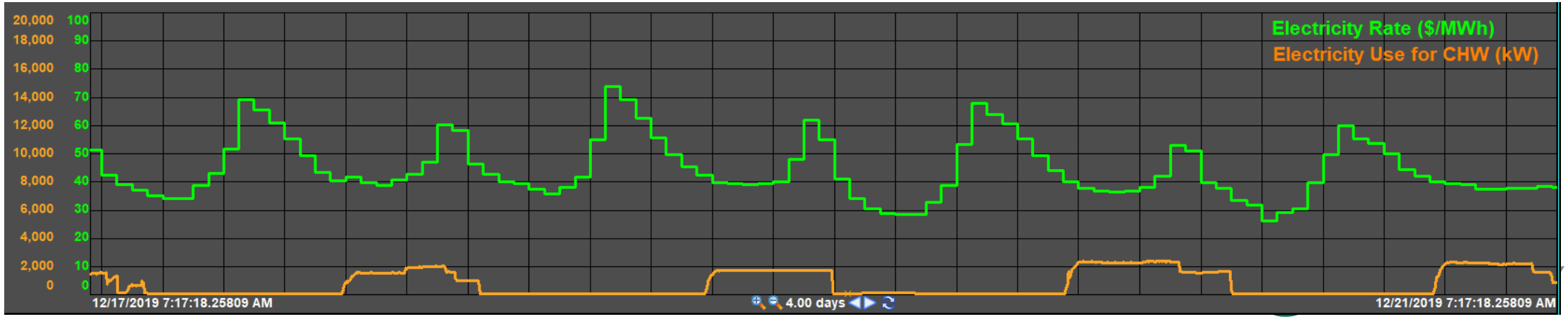
The peak demand in the next 24 hours will be **1,412 Tons** at **18:00, Jan.7** with a CHW flow rate of **3,056 gpm**

# Plant Optimization: Rate-Driven TES Dispatch

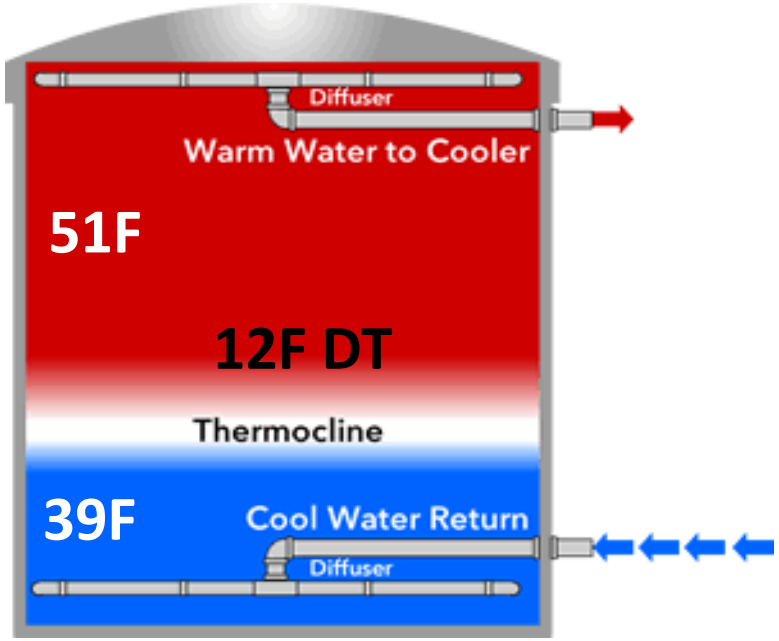
## Prior to training



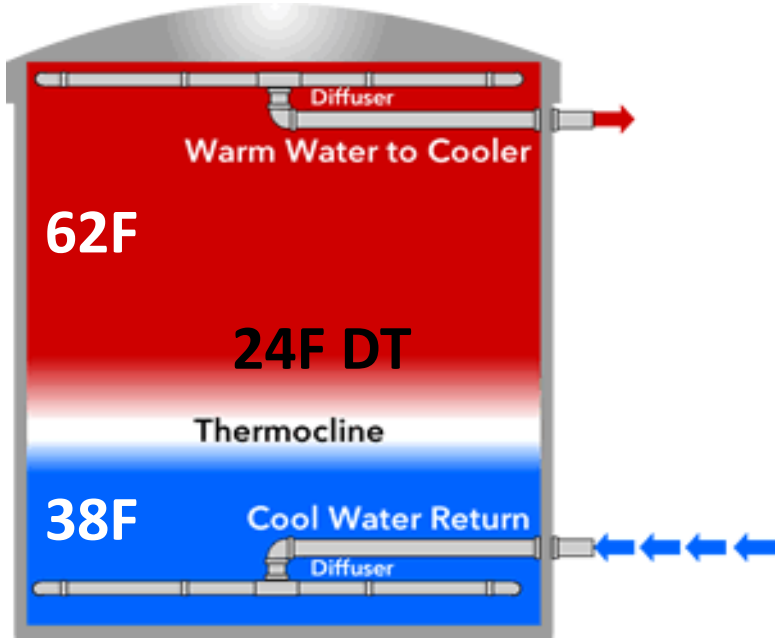

## Post Training



# Plant Optimization: Increase the TES Battery




- 4.8M Gallons
- 40,000 ton-hr
- 39/51 °F CHWS/R
- 12 °F ΔT



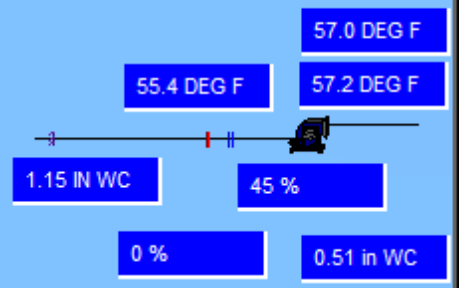

- 4.8M Gallons
- 80,000 ton-hr
- 38/60 °F CHWS/R
- 24 °F ΔT

# Building Optimization: New ≠ Good

# Static Pressure and SAT Reset

SIEMENS System: MTWF Building

## Current System Values




## Quick Links


## OA Conditions

**Temperature**
*69.6 DEG F*

**Humidity**
*40.63 % RH*

**Enthalpy**
*23.3 Btu/Lb*

**Dewpoint**
*44.11 Deg F*

## PPCL Links

## Static Pressure - Setpoints & Details

| Tuning Setpoints | |
|---|---|
| Min Static: | 0.50 in WC |
| Max Static: | 1.75 in WC |
| Max Terminal: | 95 PCT |
| Stg Up Time: | 180 Secnds |
| Stg Dn Time: | 185 Secnds |

**CULPRIT** 8

**Mode** ON

| Decision Values | |
|---|---|
| MINIMUM: | 17 PCT |
| AVERAGE: | 48 PCT |
| MAXIMUM: | 86 PCT |
| COUNT: | 24 # |
| Eff Static SP: | 0.50 IN WC |

| Box ID | Enable Reset | Damper Position |
|---|---|---|
| 1 | Enabled | 33.60 PCT |
| 2 | Enabled | 33.60 PCT |
| 3 | Disabled | 29.60 PCT |
| 4 | Disabled | 68.80 PCT |
| 5 | Enabled | 70.00 PCT |
| 6 | Enabled | 81.60 PCT |
| 7 | Enabled | 56.80 PCT |
| 8 | Enabled | 85.20 PCT |
| 9 | Enabled | 61.20 PCT |
| 10 | Enabled | 28.80 PCT |
| 11 | Enabled | 40.40 PCT |
| 12 | Enabled | 33.60 PCT |
| 13 | Disabled | 100.00 PCT |
| 14 | Disabled | 33.60 PCT |
| 15 | Disabled | 39.60 PCT |

| Box ID | Enable Reset | Damper Position |
|---|---|---|
| 21 | Enabled | 42.80 PCT |
| 22 | Enabled | 53.60 PCT |
| 23 | Enabled | 35.20 PCT |
| 24 | Enabled | 16.40 PCT |
| 25 | Enabled | 52.80 PCT |
| 26 | Enabled | 56.00 PCT |
| 27 | Enabled | 48.80 PCT |
| 28 | Enabled | 73.20 PCT |
| 29 | Enabled | 34.40 PCT |
| 30 | | |
| 31 | | |
| 32 | | |
| 33 | | |
| 34 | | |
| 35 | | |

## Temperature - Setpoints & Details

| Tuning Setpoints | |
|---|---|
| MIN SAT: | 55.0 Deg F |
| MAX SAT: | 65.0 Deg F |
| Max Terminal: | 95 PCT |
| Stg Up Time: | 300 Secnds |
| Stg Dn Time: | 305 Secnds |

**CULPRIT** 17

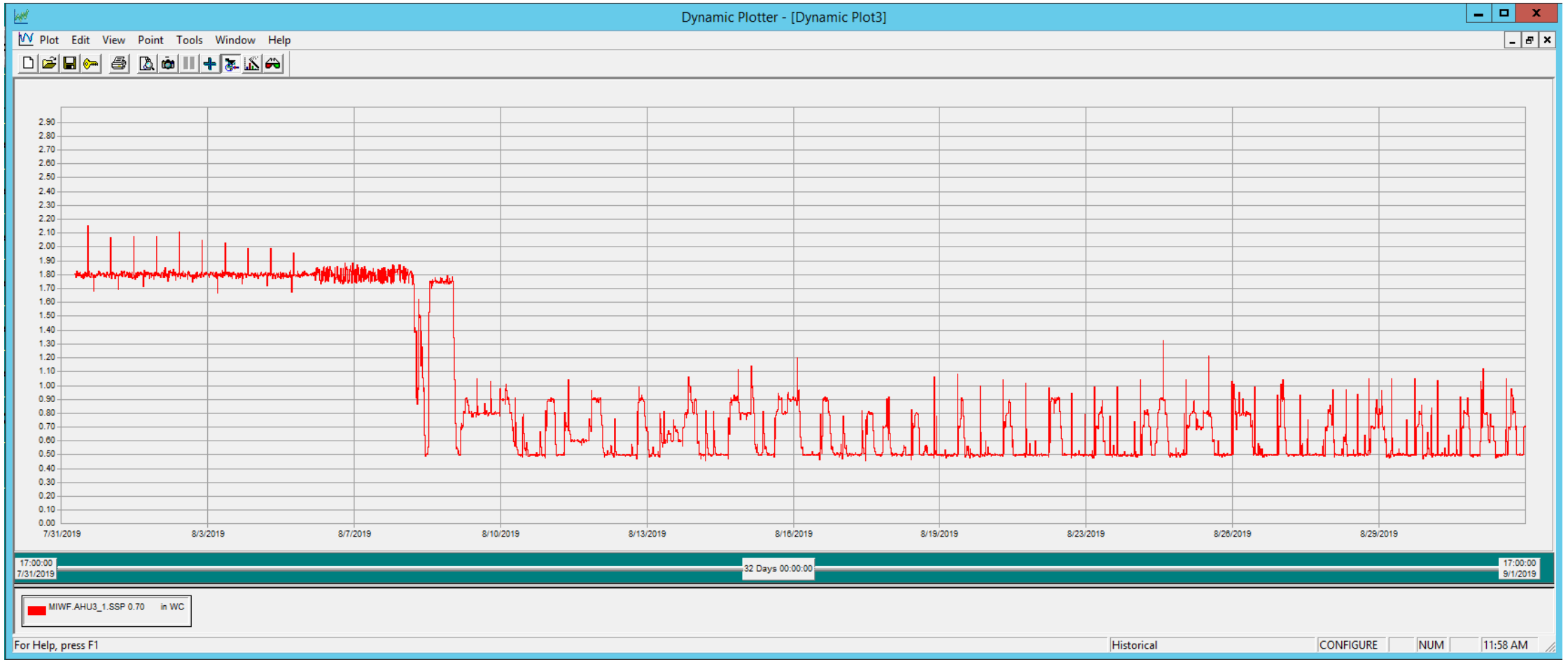
**Mode** ON

| Decision Values | |
|---|---|
| MINIMUM: | 0 PCT |
| AVERAGE: | 15 PCT |
| MAXIMUM: | 96 PCT |
| COUNT: | 24 # |
| Error Tolerance: | 1.50 Deg F |

| Box ID | Enable Reset | Input Value |
|---|---|---|
| 1 | Enabled | 0.00 PCT |
| 2 | Enabled | 0.00 PCT |
| 3 | Disabled | 0.00 PCT |
| 4 | Disabled | 0.00 PCT |
| 5 | Enabled | 0.00 PCT |
| 6 | Enabled | 16.67 PCT |
| 7 | Enabled | 0.00 PCT |
| 8 | Enabled | 0.00 PCT |
| 9 | Enabled | 0.00 PCT |
| 10 | Enabled | 0.00 PCT |
| 11 | Enabled | 29.60 PCT |
| 12 | Enabled | 0.00 PCT |
| 13 | Disabled | 89.60 PCT |
| 14 | Disabled | 0.00 PCT |
| 15 | Disabled | 0.00 PCT |

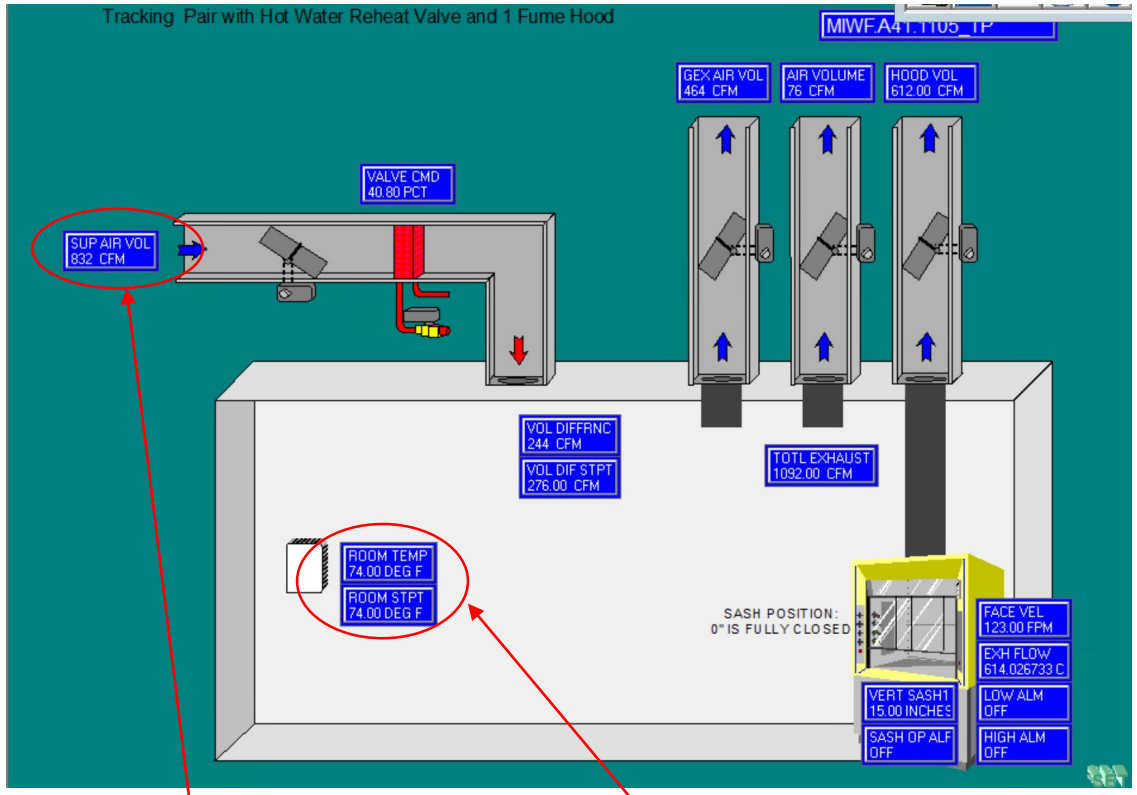
| Box ID | Enable Reset | Input Value |
|---|---|---|
| 21 | Enabled | 0.00 PCT |
| 22 | Enabled | 0.00 PCT |
| 23 | Enabled | 0.00 PCT |
| 24 | Enabled | 0.00 PCT |
| 25 | Enabled | 0.00 PCT |
| 26 | Enabled | 0.00 PCT |
| 27 | Enabled | 0.00 PCT |
| 28 | Enabled | 94.00 PCT |
| 29 | Enabled | 0.00 PCT |
| 30 | | |
| 31 | | |
| 32 | | |
| 33 | | |
| 34 | | |
| 35 | | |

# Building Optimization: Static Pressure Reset



# Lab Control – Code Optimization

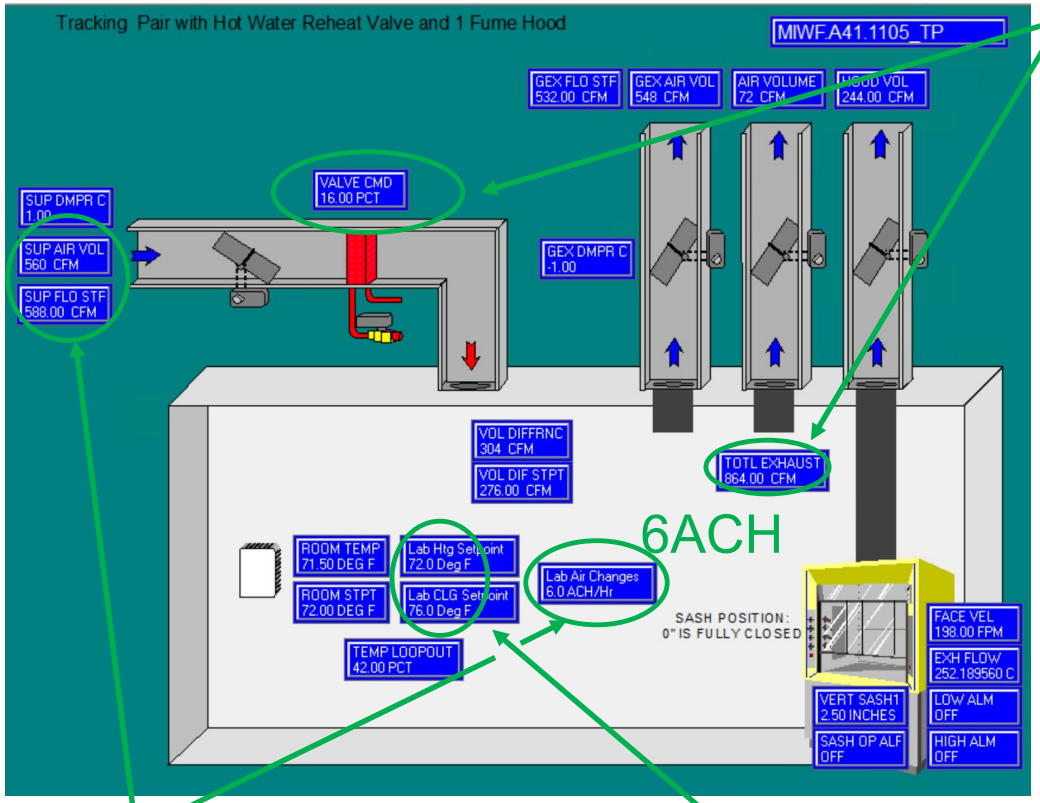
## Before




Minimum does not compensate for hood airflow, over-ventilates in heating mode (7.2 ACH)

Does not allow for a heating/cooling space temp deadband

## After



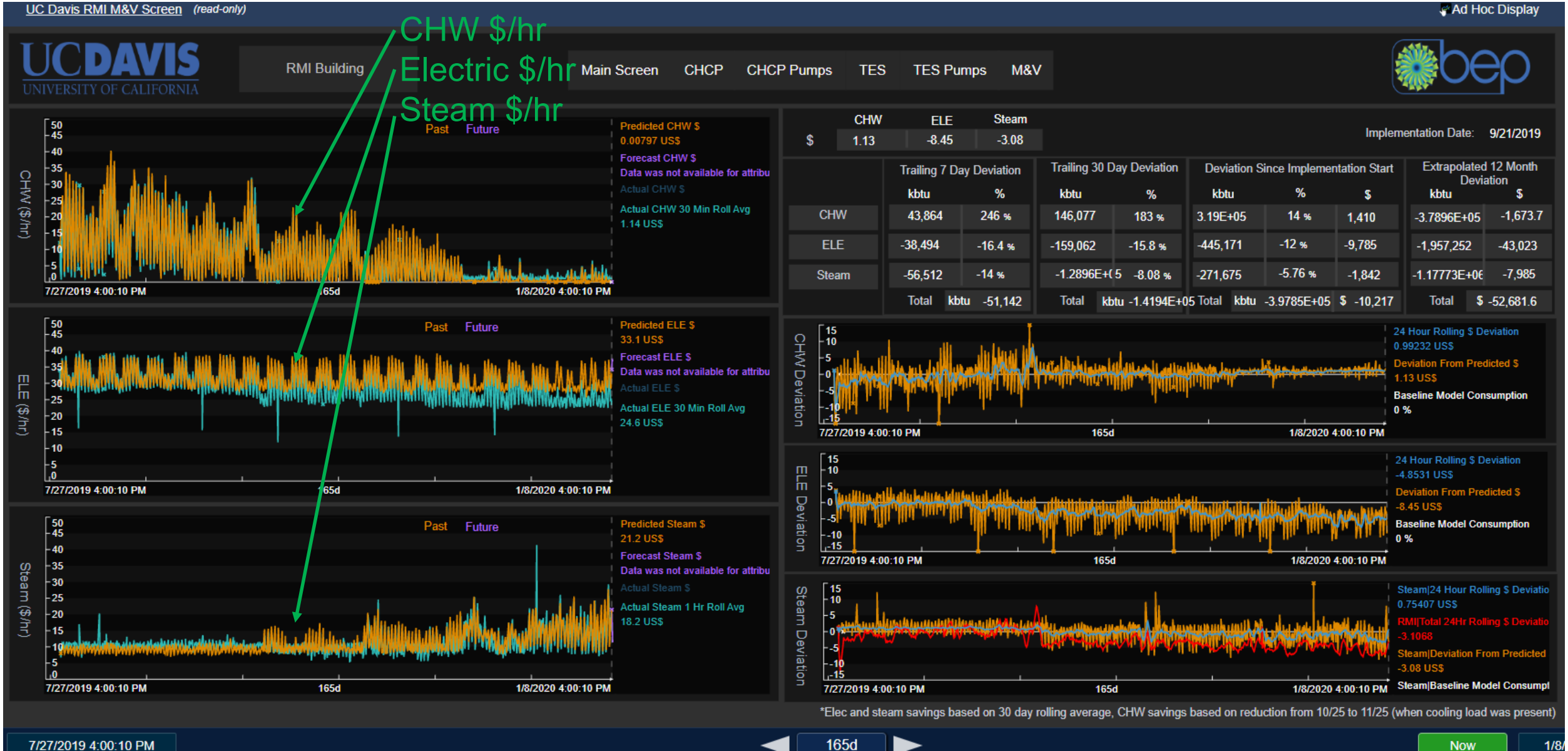

Less Reheat
Less EA/SA CFM

6ACH

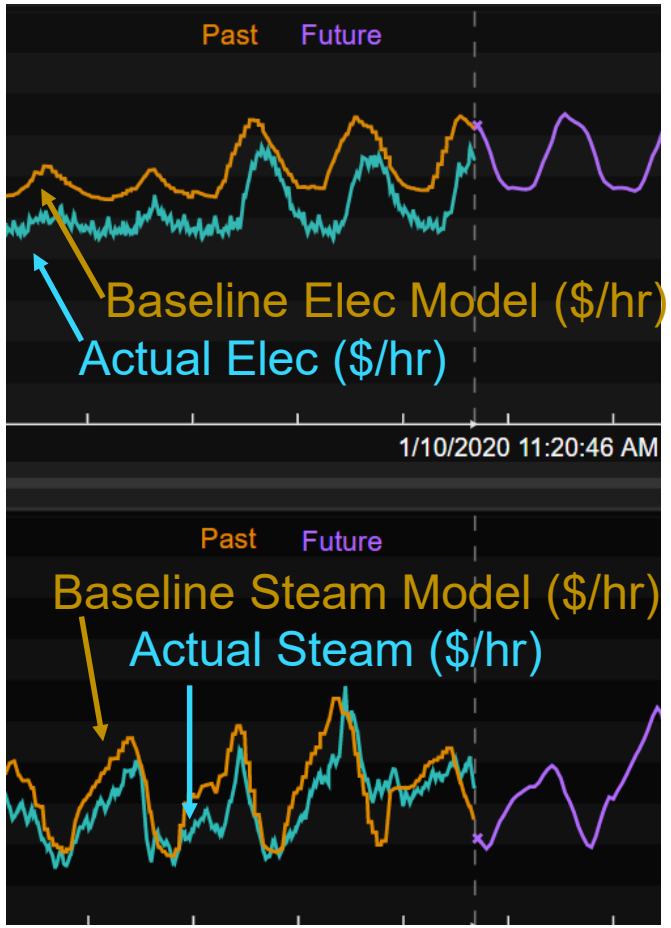
Displays and controls down to min ACH setpoint (6 ACH, 18% Reduction)

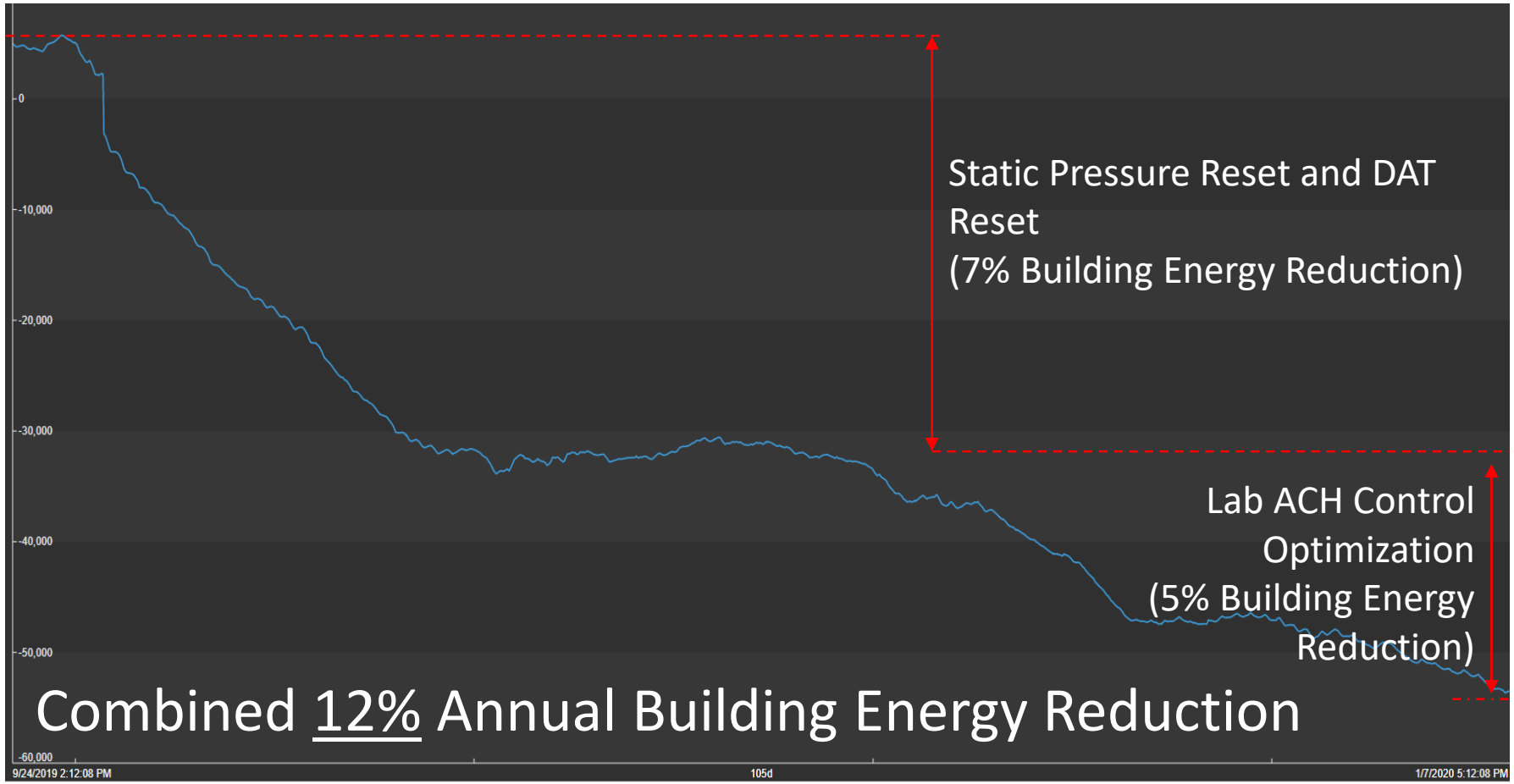
Allows for a heating/cooling space temp deadband

# “Live M&V” Using Machine Learned Model



# Extrapolated Annual Savings



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