Terascale Simulation Facility (TSF)

Power Efficiency Improvements to Achieve Petascale and Exascale Computing

Gov Energy 2010 Sustainability Track - Case Studies in Existing Buildings

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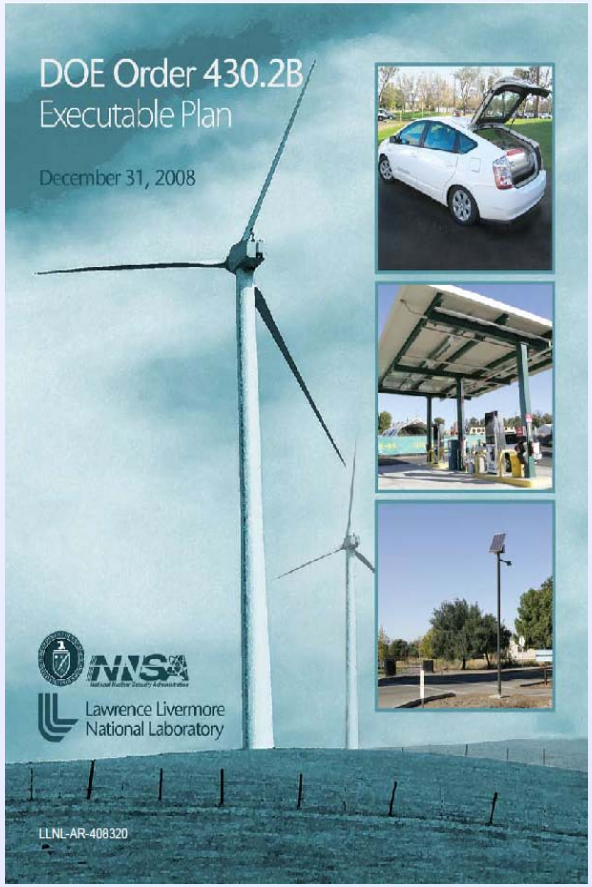
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 • LLNL-PRES- 432828

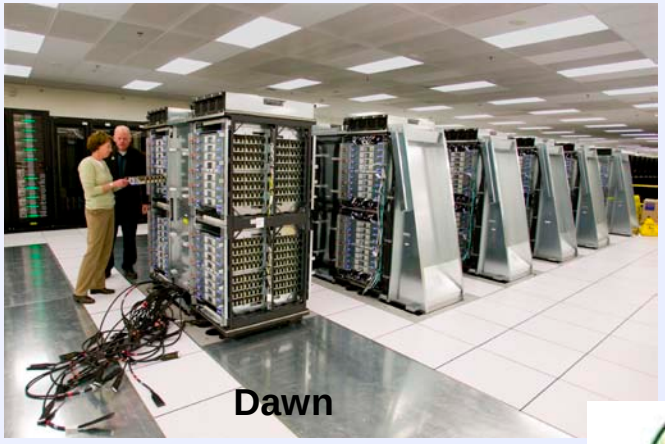
Computation strives to reduce energy consumption and ultimately reduce operating costs

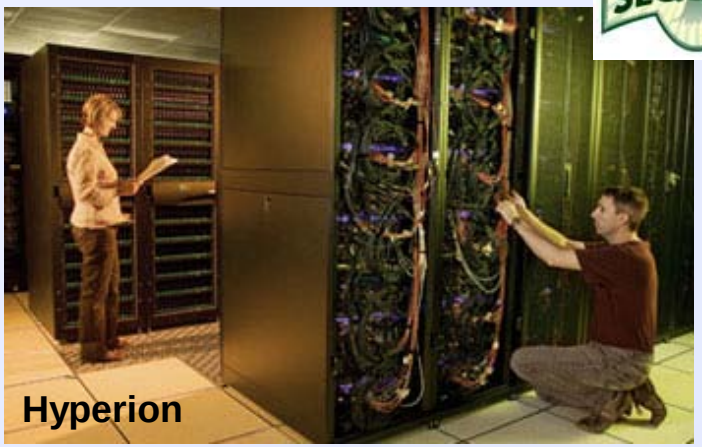
- Energy costs are increasing
  - Existing energy contracts are capped
- Energy conservation is critical to improve efficiencies
- Reduce operational costs
  - Operational efficiencies are vital to future success
- Assist the Laboratory to achieve Executive Order DOE 430.2B
  - Reduce energy intensity 30% by 2015 from baseline (FY03)



Computation creates efficiencies and turns Megawatts into PetaFLOPS

- Capitalize on flexible and scalable infrastructure of the facility and computational efficiencies
- Extensive benchmarking
- Comprehensive computational fluid dynamics (CFD)
- Improved operational efficiencies
  - DOE FEMP 2009 Energy Award
  - LEED Gold Certified December, 2009
- Position infrastructure for the future – Sequoia, Hyperion, etc.





TSF computer room design is extremely efficient

- Single story, two-level design
- Pressurized plenum
  - (30) 80,000 CFM air handlers
- Common Supply/Return System
  - Efficient design
  - Improved operational abilities
- Mechanical and electrical systems co-located to reduce losses and improve efficiencies

TSF has an excellent Power Usage Effectiveness (PUE) of 1.32

Power In

Total Facility Power

Power

Switchgear
UPS
Battery Backup

Cooling

Cooling Towers
Chillers
Air Handlers

Power Out

Total HPC Equipment Power

Servers
Racks
Platforms
Networks
File Systems
Storage

1.32

PUE	DCiE	Level of Efficiency
3.0	33%	Very Inefficient
2.5	40%	Inefficient
2.0	50%	Average
1.5	67%	Efficient
1.2	83%	Very Efficient

PUE = Total Facility Power / IT Equipment Power
DCiE = IT Equipment Power / Total Facility Power
Source: Green Grid

Strive to be the "Best in Class"

Benchmarking tools were utilized to identify prospective energy saving initiatives within the computer rooms

- Worked with DOE Industrial Technologies Program and Lawrence Berkeley Laboratory (LBL)
  - Identified energy savings through benchmarking tools

http://hightech.lbl.gov/datacenters.html

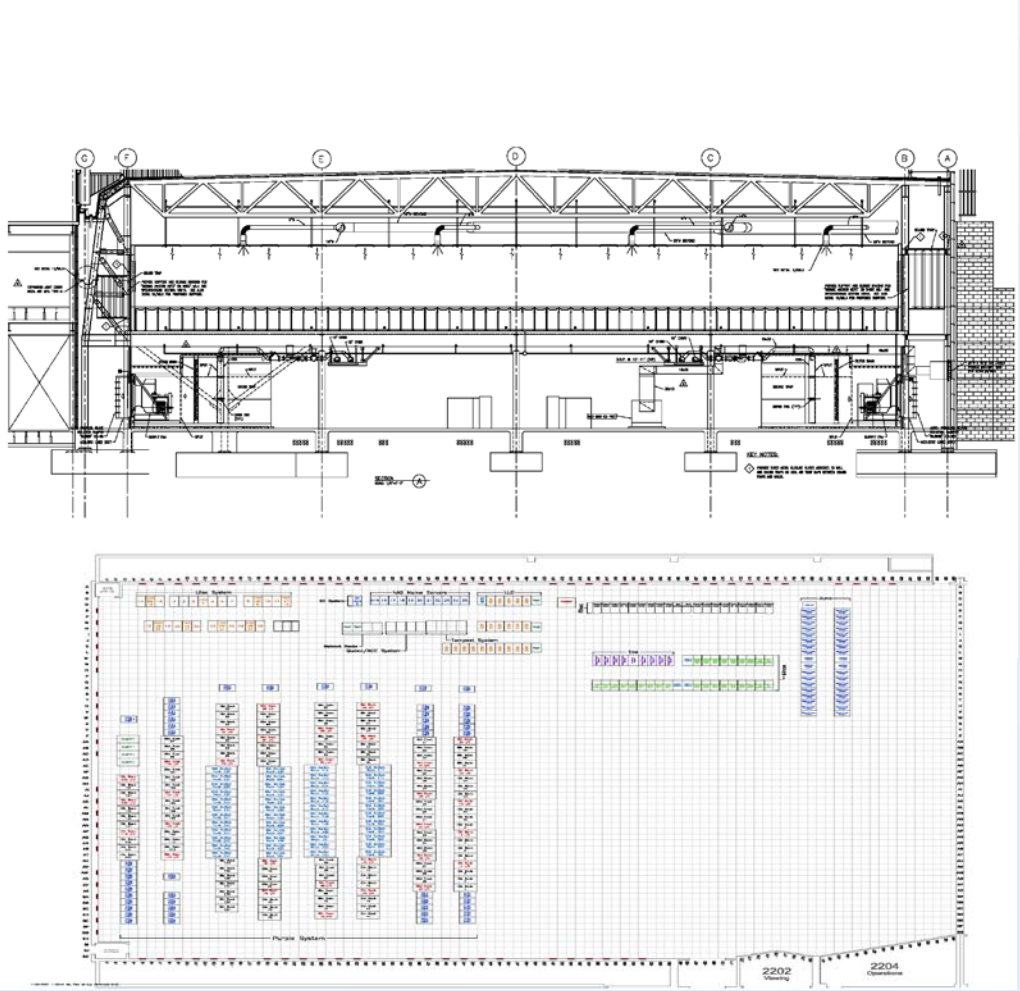
- DOE FEMP now offers DC Pro Tools, an on line benchmarking tool

- Potential energy savings
  - Raise air supply temperature
  - Raise chilled water supply
  - Address air leakage issues
  - Rebalance the computer floor

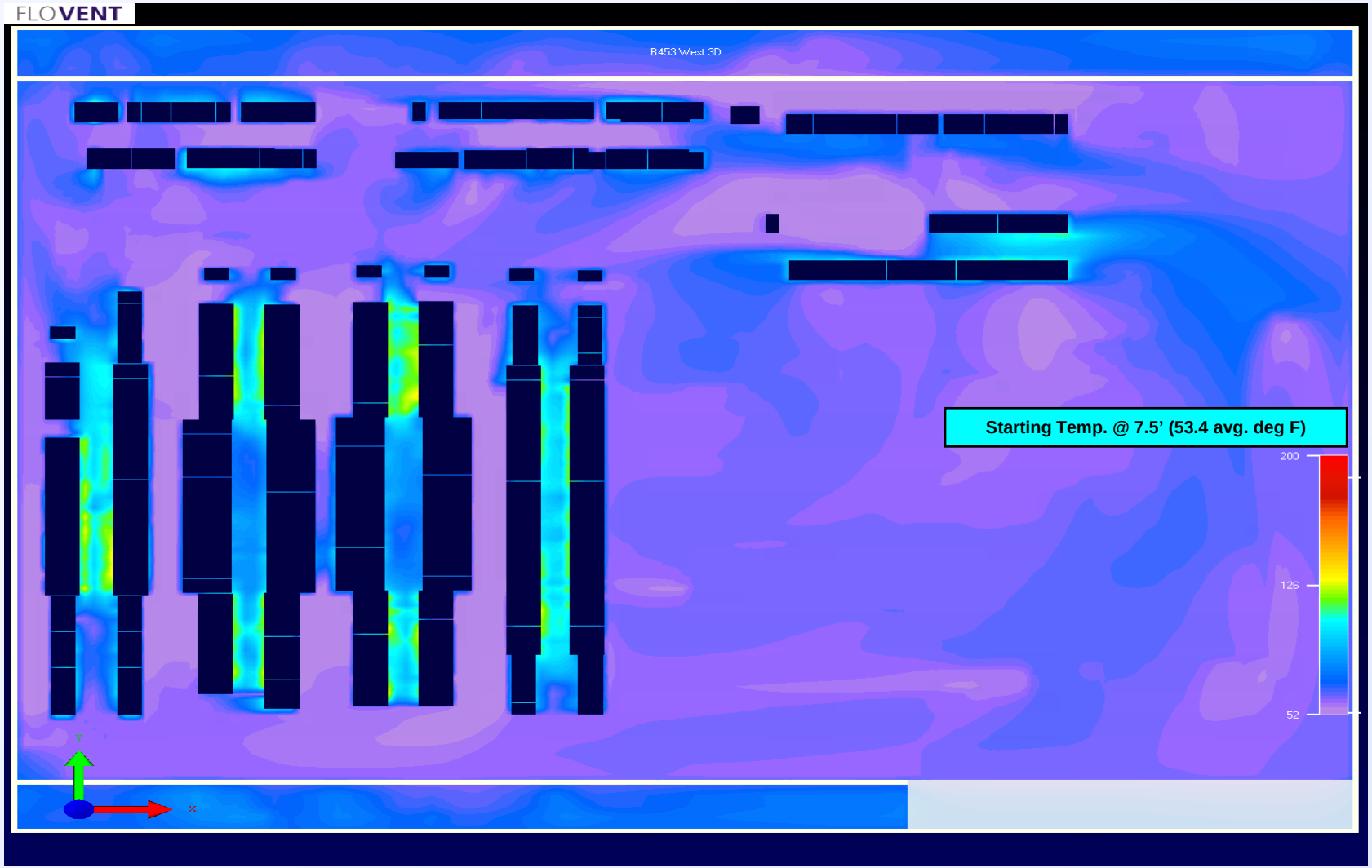
LLNL B453 Data Center Performance Metrics				
ID	Name	Unit	Data Required	Data
B1	Source Energy Use Intensity	Source BTU/sf-yr	dB1- Electrical Energy Use (kWh)	36,965,898
			dB2- Natural Gas Energy Use (MMBTU)	6773
			dB3- Fuel Energy Use (MMBTU)	N/A
			dG1- Data Center Gross Area (sf)	48000
			dG7- Source Energy Factors	N/A
B2	Purchased Energy Cost Intensity	Energy $/sf-yr	dB4- Purchased Energy Cost ($)	$54 per MW
			dG1- Data Center Gross Area (sf)	48000
B3	Site Energy Use Intensity	Site BTU/sf-yr	dB1- Electrical Energy Use (kWh)	36,965,898
			dB2- Natural Gas Energy Use (MMBTU)	6773
			dB3- Fuel Energy Use (MMBTU)	N/A
			dG1- Data Center Gross Area (sf)	48000
B4	Peak Electrical Load Intensity	Peak W/sf	dB5- Peak Electrical Load (kW)	11515
			dG1- Data Center Gross Area (sf)	48000
B5	Energy Effectiveness	%	dB1- Electrical Energy Use (kWh)	36,965,898
			dB2- Natural Gas Energy Use (MMBTU)	6773
			dB3- Fuel Energy Use (MMBTU)	N/A
			dP1- IT Equipment Power: Actual (kW)	27,586,491
B7	Redundancy Level - HVAC	-	dG5- Redundancy Level - HVAC	N+2

A comprehensive computational fluid dynamic (CFD) model was performed to analyze airflow patterns in TSF

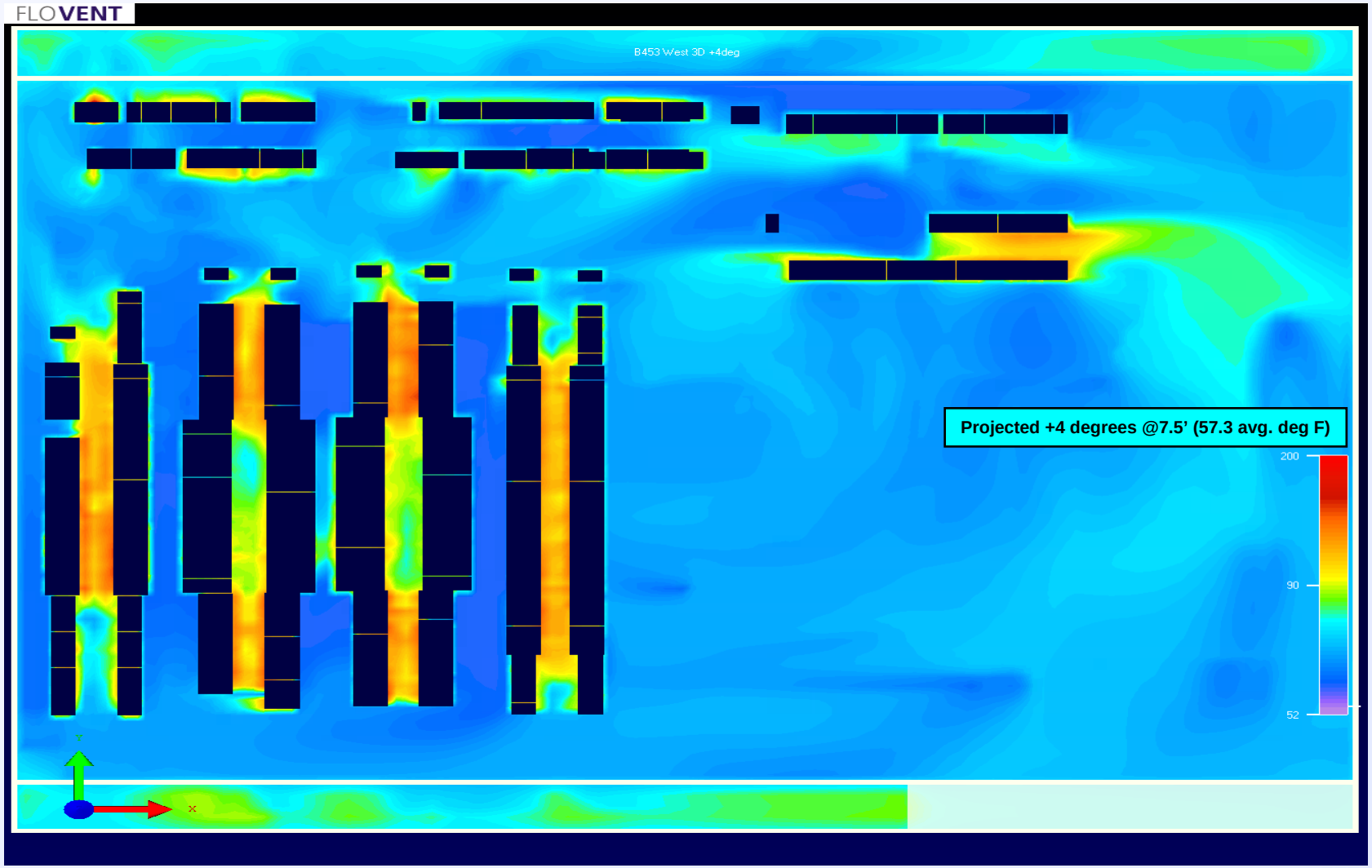
- Physical layouts imported
- Baseline CFD
  - Starting temperature 53.4F
- Modeled airflow
  - 2” Above finished floor (AFF) – inlet of racks
  - 7.5’ AFF – above the racks
  - 10.5 ’AFF – ceiling



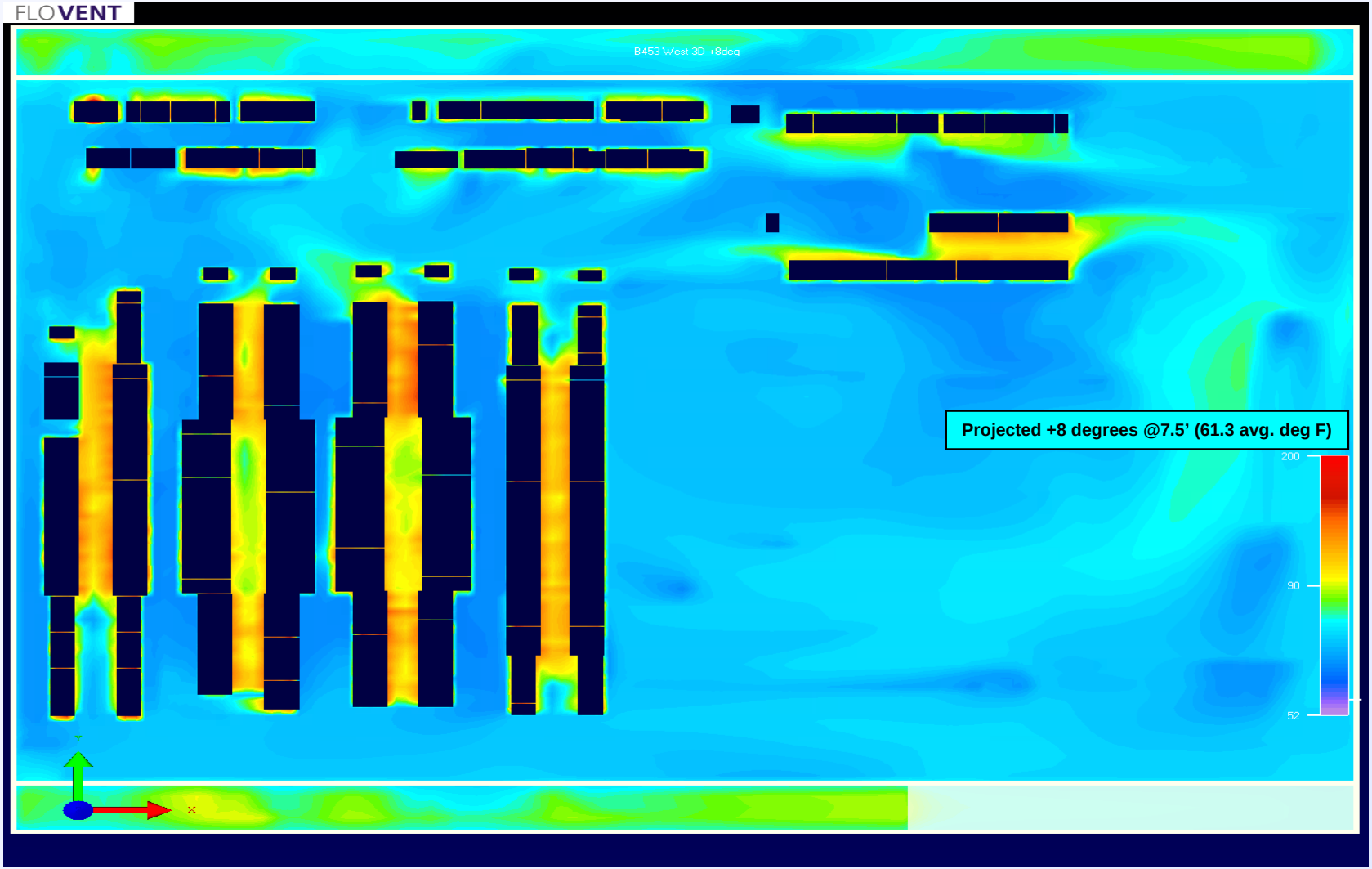
The TSF west room was baselined with a starting temperature of 53.4°F avg. and modeled at 2”, 7.5’ and 10.5’ AFF



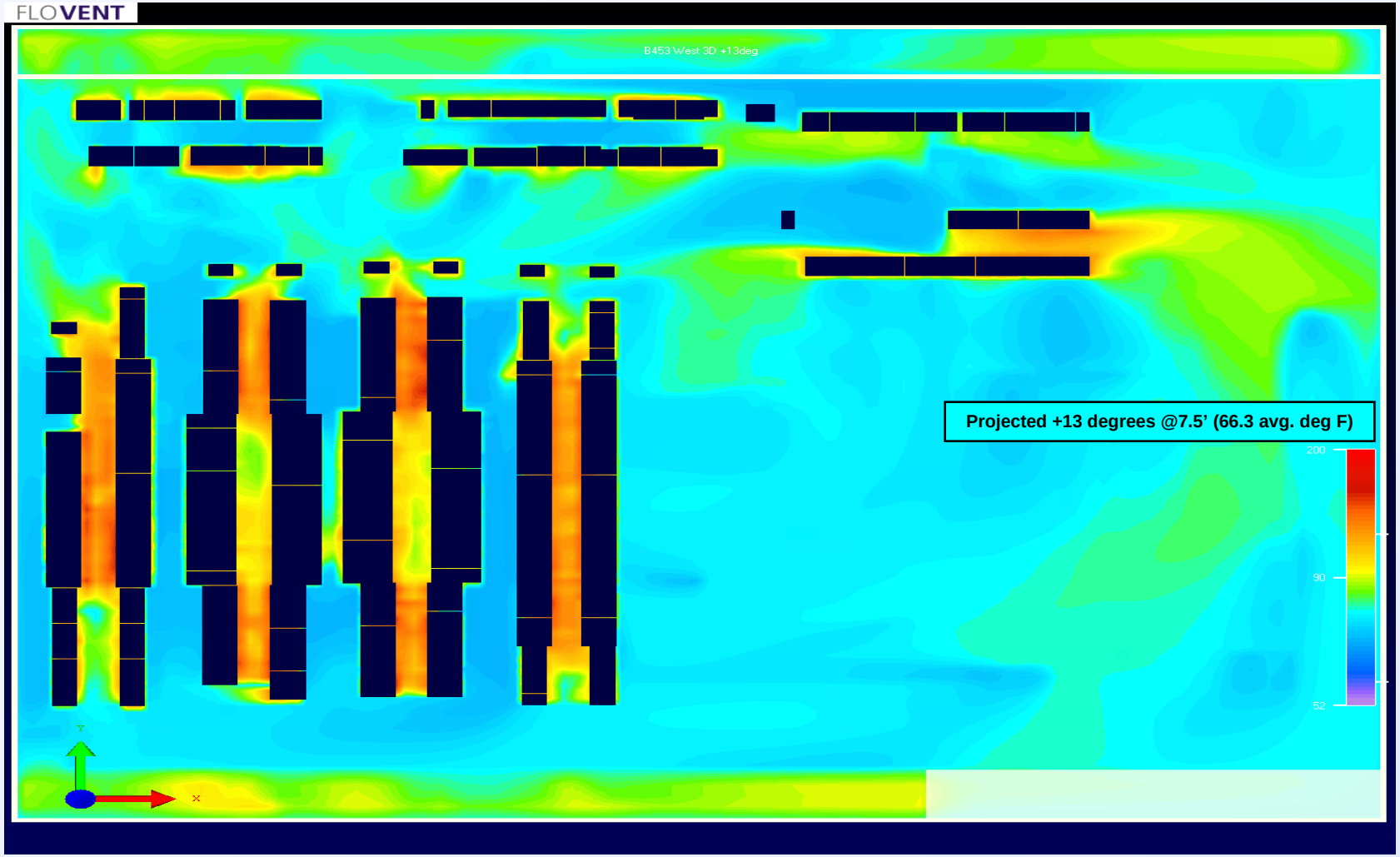
The TSF west room was modeled with a projected temperature of 57.3°F avg. 7.5' AFF



The TSF west room was modeled with a projected temperature of 61.3°F avg. 7.5' AFF



The TSF west room was modeled with a projected temperature of 66.3°F avg. 7.5' AFF



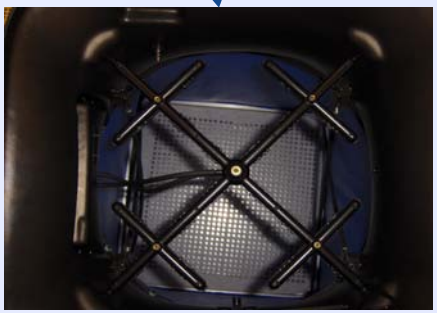
After benchmarking and CFD modeling, changes were made in the TSF without negative operational impact

- Supply air temperature increased from 53.4º F to 60.4º F (West) and 64º F (East)
- Supply chilled water temperature increased: 43º F to 51º F
- Air leakage addressed - 450,000 cubic feet per minute (CFM)
  - Building penetrations sealed
  - Pillows and panels installed at rack level
  - Louvered perforated tiles replaced with solid tiles

Ongoing Savings

Initiative	Savings (kwh/yr.)	$/kwh	Total Savings ($)/yr.
Raise Air Supply Temperature	32,307,692	0.065	$ 2,100,000
Raise Chilled Water Supply Temperature	15,677,704	0.065	$ 1,019,051
Air Leakage (2) Air Handlers Off Line	542,211	0.065	$ 35,244
Total			**$ 3,154,295**

Measure closed louvered perforated tile leakage = 100 to 200 cfm/tile



TSF computer room power easily scales to 30MW

- Capitalize on the electrical/mechanical system efficiencies
- Return operational energy savings back to the computers
- Capitalize on the computational efficiencies (TF/MW and SF/TF)

Platform	MW	SF	TF	TF/MW	SF/TF
Purple	4.80	8000.00	100	21	80.0
BG/L	2.50	4000.00	600	240	6.7
Dawn	2.00	2000.00	500	250	4.0
Sequoia	9.60	4000.00	20000	2083	0.2

Turn MW to PetaFLOPs

TSF was (LEED) Gold Certified on December 24, 2009 using the Operations and Maintenance v2 rating system

LEED-EB

- Leadership in Energy and Environmental Design (LEED) EB O&M focuses on the performance of building systems and their maintenance in a facility that has been in continuous operation for at least one year.

LEED for Existing Buildings: Operations & Maintenance
Registered Project Checklist

Project Name: B453 TeraScale Simulation Facility

Project Address: 7000 East Avenue, Livermore, CA 94550

Yes	?	No		
56	0	1	Project Totals (Pre-Certification Estimates)	92 Points
GOLD			**Certified**: 34-42 points **Silver**: 43-50 points **Gold**: 51-67 points **Platinum**: 68-92 points	

Yes	?	No			
7	0	0	Sustainable Sites		12 Points
		0	Credit 1	**LEED Certified Design and Construction**	1
1		0	Credit 2	**Building Exterior and Hardscape Management Plan**	1
1			Credit 3	**Integrated Pest Mgmt, Erosion Control, and Landscape Mgmt Plan**	1
1	0		Credit 4	**Alternative Commuting Transportation**	1 to 4
			--> Credit 4.1	10% Reduction	1
			Credit 4.2	25% Reduction	2
			Credit 4.3	50% Reduction	3
			Credit 4.4	75% Reduction or greater	4
		0	Credit 5	**Reduced Site Disturbance**, Protect or Restore Open Space	1
1	0		Credit 6	**Stormwater Management**	1
1			Credit 7.1	**Heat Island Reduction**, Non-Roof	1
1			Credit 7.2	**Heat Island Reduction**, Roof	1
1			Credit 8	**Light Pollution Reduction**	1

The LEED-EB Process

1

Which credits should we pursue?

Evaluate choices based on appropriateness, cost and time constraints

2

What information do we need?

Identify all data needed for LEED submittal package, credit-by-credit

3

Is the information readily available?

Determine if sub-metering is needed and identify subject matter experts/team members to track and gather data

4

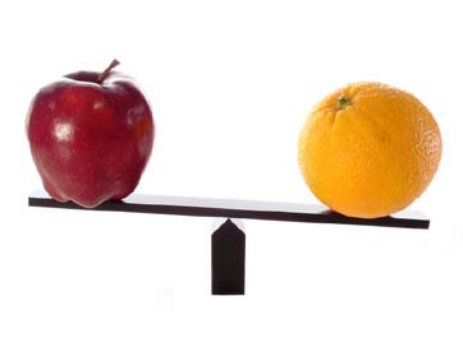
Are we missing anything?

A simple policy change or a minor systems repair is sometimes all that is needed to capture a credit. Larger proposed changes need to be evaluated by facility management for appropriateness.

Benchmarking within the LEED-EB Rating System

- LEED uses EPA's Portfolio Manager and Energy Star programs to benchmark buildings.
- Datacenters or high performance computing centers do not currently fit any available building type in either the Portfolio Manager system or the CBECS database.

How do you benchmark within LEED-EB when your building does not align with Portfolio Manager's building database?



Create your own benchmarking database comprised of similar computing centers

TSF was compared to 3 on-site Tera-flop capable centers

Benchmarking within the LEED-EB Rating System

Source EUI = Total energy consumed on-site in kBtu/sf

LEED-EB uses a building's source Energy Use Intensity (EUI) as the basis for comparing energy efficiency.

How do you compare high performance computing centers within LEED-EB when the buildings vary widely in square footage, energy usage and computation capability?

Determine your basis of comparison

Determine your normalizing factors

Basis of Comparison : TSF vs. Datacenters 2, 3 & 4

How much power (kWh) would Datacenters 2, 3, & 4 have used to perform the same work (teraflops) as TSF?

Normalizing Factors:
- Computation Capability
- Square Footage Occupancy

are used to calculate

Normalized Annual Whole Building Electricity Use

Normalized Annual Whole Building Electricity Use

is plugged into EAc1:Opt.C3 spreadsheet to determine

Source EUI

	Datacenter 2	Datacenter 3	Datacenter 4	TSF (B453)
Whole Building (sf)	51,398	11,783	11,087	241,197
Whole Building Electricity Use (kWh)	26,779,436	6,052,547	1,883,976	98,336,717
Whole Building Natural Gas use (ccf) [Not used in Datacenters]	19,010	4,753	4,321	95,054
Data Center (sf) [computers and cooling]	35,000	7,000	8,500	121,607
Data Center Electricity Use (annual kWh) [computers and cooling]	16,057,080	3,600,360	902,280	89,771,810
Percentage of Datacenter in Use (%)	75%	75%	90%	60%
Teraflops	187.0	110.0	46.0	1583.0
MW	1.8	0.4	0.1	10.2
sf/Teraflops	140.4	47.7	166.3	46.1
Teraflops/MW	102.0	267.6	446.6	154.5
kWh (data center only)/TF	85,867	32,731	19,615	56,710
Normalized for power consumption per unit of processing power and for % of datacenter in use compared to B453 (annual kWh)	108,741,637	41,449,963	20,700,134	89,771,810
TOTAL Non-Data Center sf including HVAC/Sppt.	16,398	4,783	2,587	119,590
TOTAL Non-Data Center Natural Gas Use (annual ccf)	19,010	4,753	4,321	95,054
TOTAL Non-Data Center Electricity Use (annual kWh)	10,722,356	2,452,187	981,696	8,564,907
GRAND TOTAL **Whole Building** Normalized Electricity Use	119,463,993	43,902,150	21,681,830	98,336,717

Lessons Learned from the LEED-EB Certification Process

Detailed energy consumption data is the key to attaining nearly one-third of all available LEED-EB credits in a "gold" level submission package.

TSF has a sophisticated Building Automation System that tracks all building systems' performance in real time.

TSF is metered at the utility level and the computational load is sub-metered down to 100 kW.

Achieving "Gold" LEED-EB Certification: Policy Changes and Equipment Installation

Monitoring and metering systems can help your building run efficiently today and simplify your pursuit of LEED-EB credits.

Meter and sub-meter all energy consumption and track and record all readings: 1 year of continuous data is needed for LEED-EB.

Tweaking heating and cooling systems' set-points and run times maximizes energy savings with minimum operational impact.

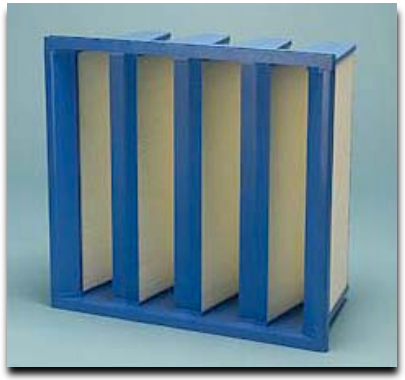
Determine optimum supply air temperatures through modeling and/or testing.

Install and use economizers to complement your datacenter cooling systems.

Achieving "Gold" LEED-EB Certification: Four Small Changes to Make Now

1

Add occupancy-sensing multi-level lighting controls

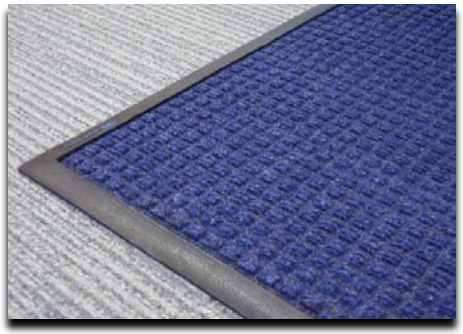


3

Replace standard HVAC filters with MERV 13 or higher filters

2

Place 10' of walk-off mats inside of all major entrances



4

Replace standard light bulbs with CFL/low-mercury light bulbs

The path forward is to continue facility audits and CFD models to implement additional operational efficiencies

- Continue to raise supply air and chilled water temperatures
- Address free cooling options
- Implement more 480V distribution to reduce losses
- Efficient liquid cooling collaboration with vendors needed to achieve next generation computing
- Implement centralized monitoring system to aggregate data to identify power management solutions
- Participate in the Energy Efficient High Performance Computing Working Group formed at SC2008 to work toward <u>common HPC benchmarking and metrics</u>

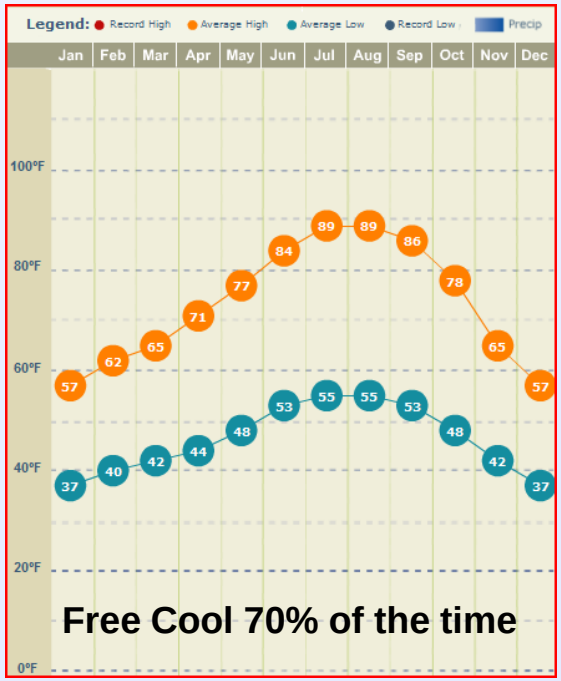
Pursuing U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) certification for B-451 (Validation period: February – July 2010) based on the current standard. USGBC has a draft proposal for certifying datacenters. Stay tuned!

Path Forward: Free Cooling Evaluations for the TSF indicate improvement of PUE to 1.15 or better

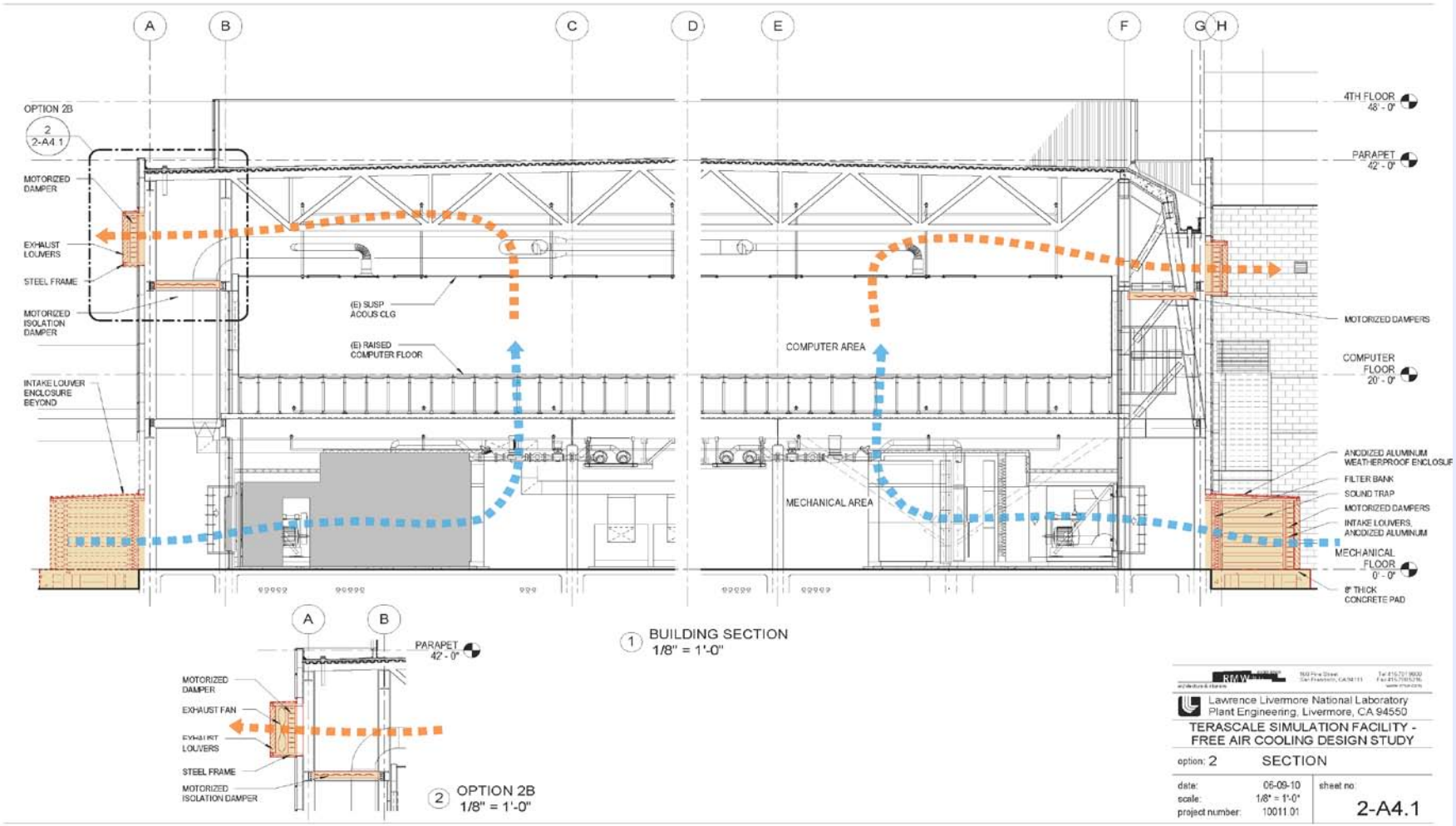
- Currently developing architectural, mechanical and controls modifications
  - Existing supply/return system is built into the north and south walls
  - Install louvers, intake dampers, humidifiers, filters and fans
  - Take advantage of seasonal/nighttime outside variations to provide cooling

Exterior Elevations

Future Free Cooling Wall



Path Forward: Free Cooling Evaluations



Path Forward: Implement centralized system of real time data from the rack to the facility to achieve power management

Create an operational, event, and real-time data management infrastructure of existing data sources

Data Sources
Rack, Equipment, Metering, Building Management

Interfaces
Hundreds of Real Time Data Streams

Manage
Gather and Evaluate Large Amounts of Data

Analyze
Convert Real Time Data

Notify
Centralized Event Notification

Visualize
View Data and Reports

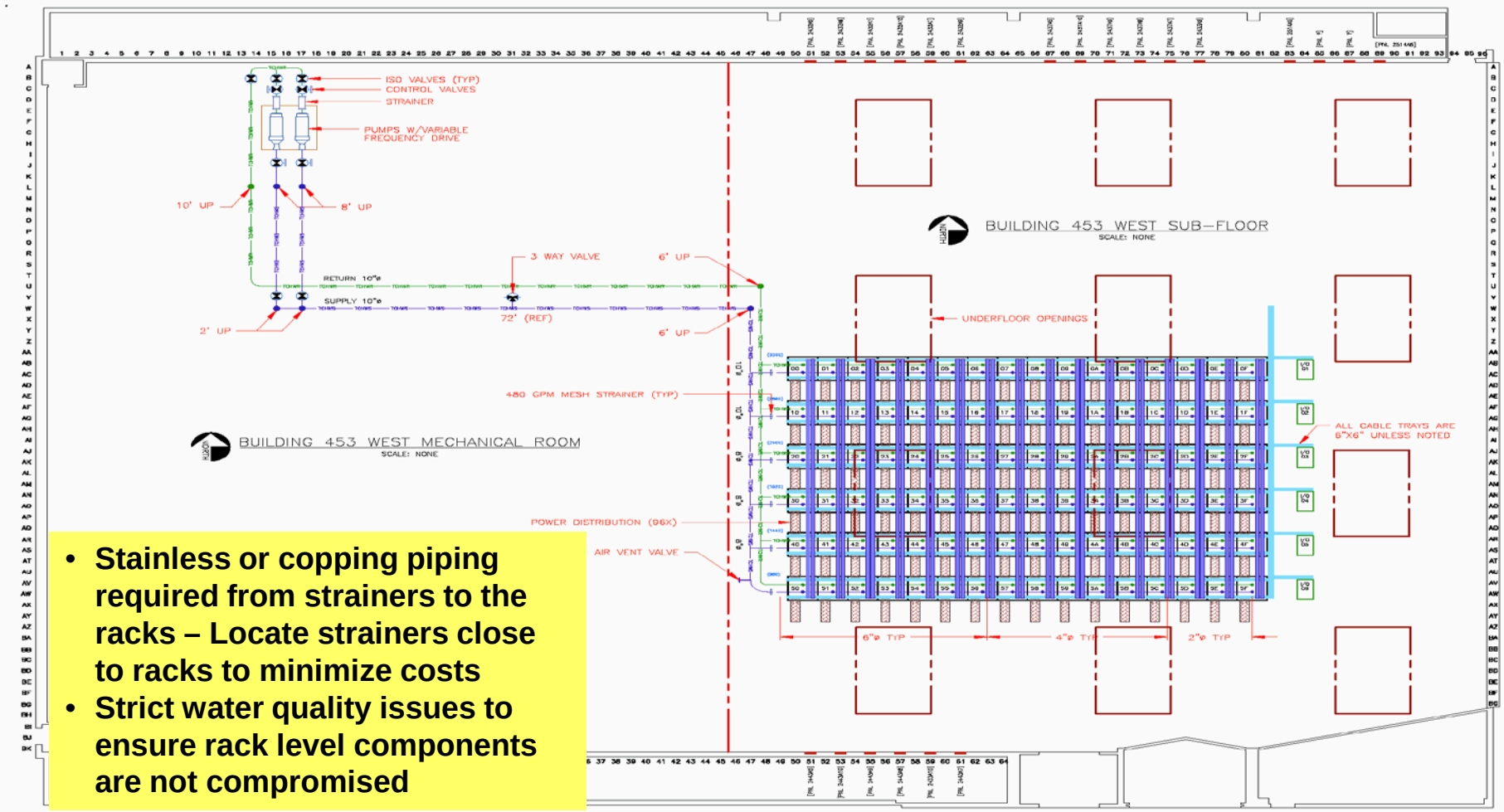
Path Forward: Sequoia Facility Infrastructure Requirements and Design Highlights

- Liquid cooling requirements: 64F to 74F to the inlet of the racks
  - Current system Condenser Water (CW) temp. range is 75F to 85F – **Too Hot**
  - Current system Chilled Water (CHW) temp. range is 50F to 58F – **Too Cold**
    - Raising supply CHW system temperature to 60F to reduce mixing requirements (*10F above published ASHRAE guidelines)*
    - Current CHW raised from 50F to 52F July, 2010 – Monitor and track to 60F
  - New tertiary CHW loop needed to meet requirements
    - Water pressure = 25 psi
    - Water temperature rise = 20F across each rack
    - GPM/rack = 30 gpm

- Required air temperature: 70F minimum to reduce condensation
  - Raising supply temperature and carefully monitoring the dew point and temperature
  - Required CFM/rack = 1200 CFM

- Required LINPACK cooling = 3800 tons (58% to 75% requirement = 2204 to 2850 tons)
- kW/rack = 100kW peak

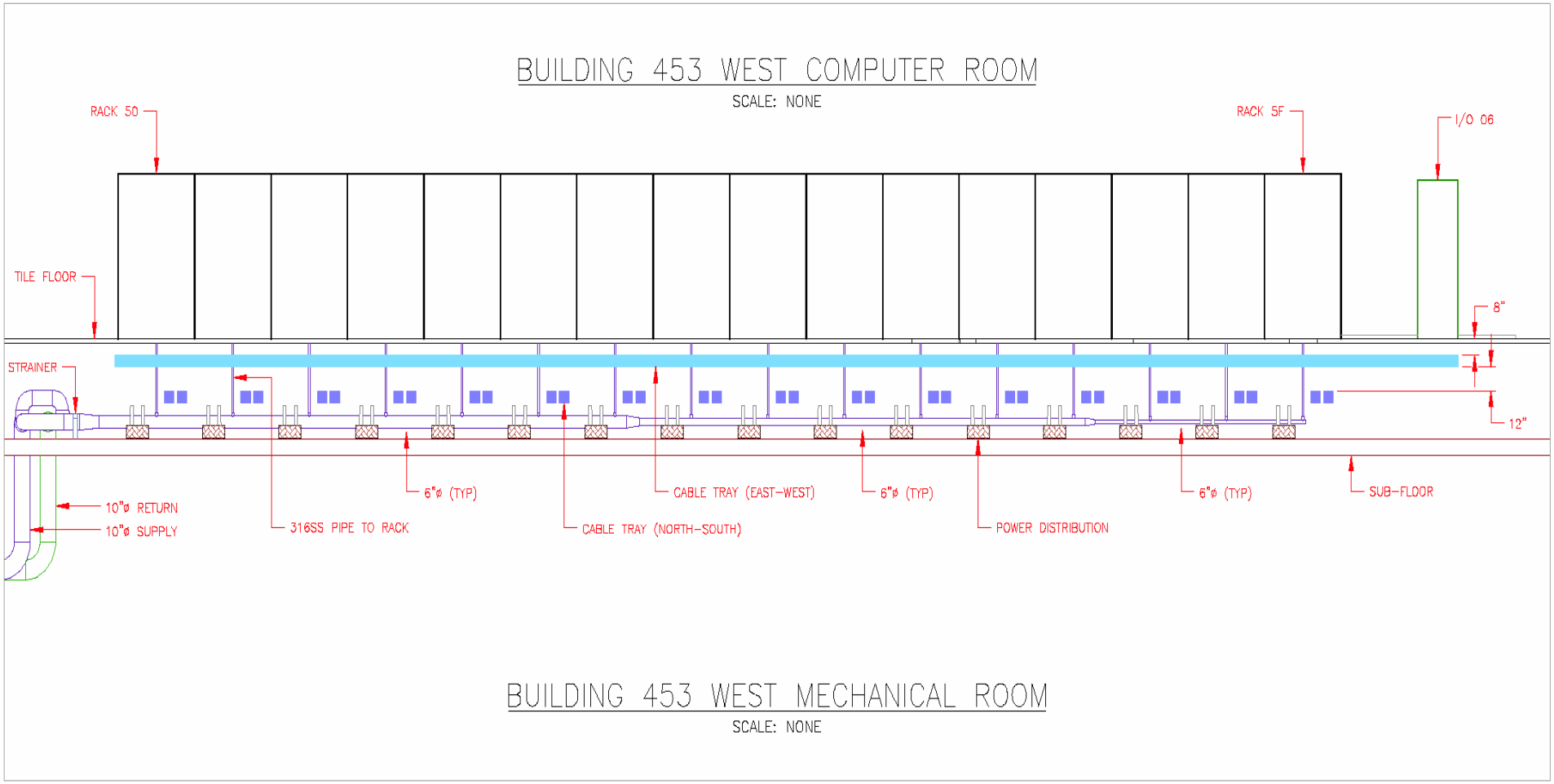
Sequoia Overall Facilities System Layout – Liquid Cooling and 480V Electrical Distribution at Rack Level



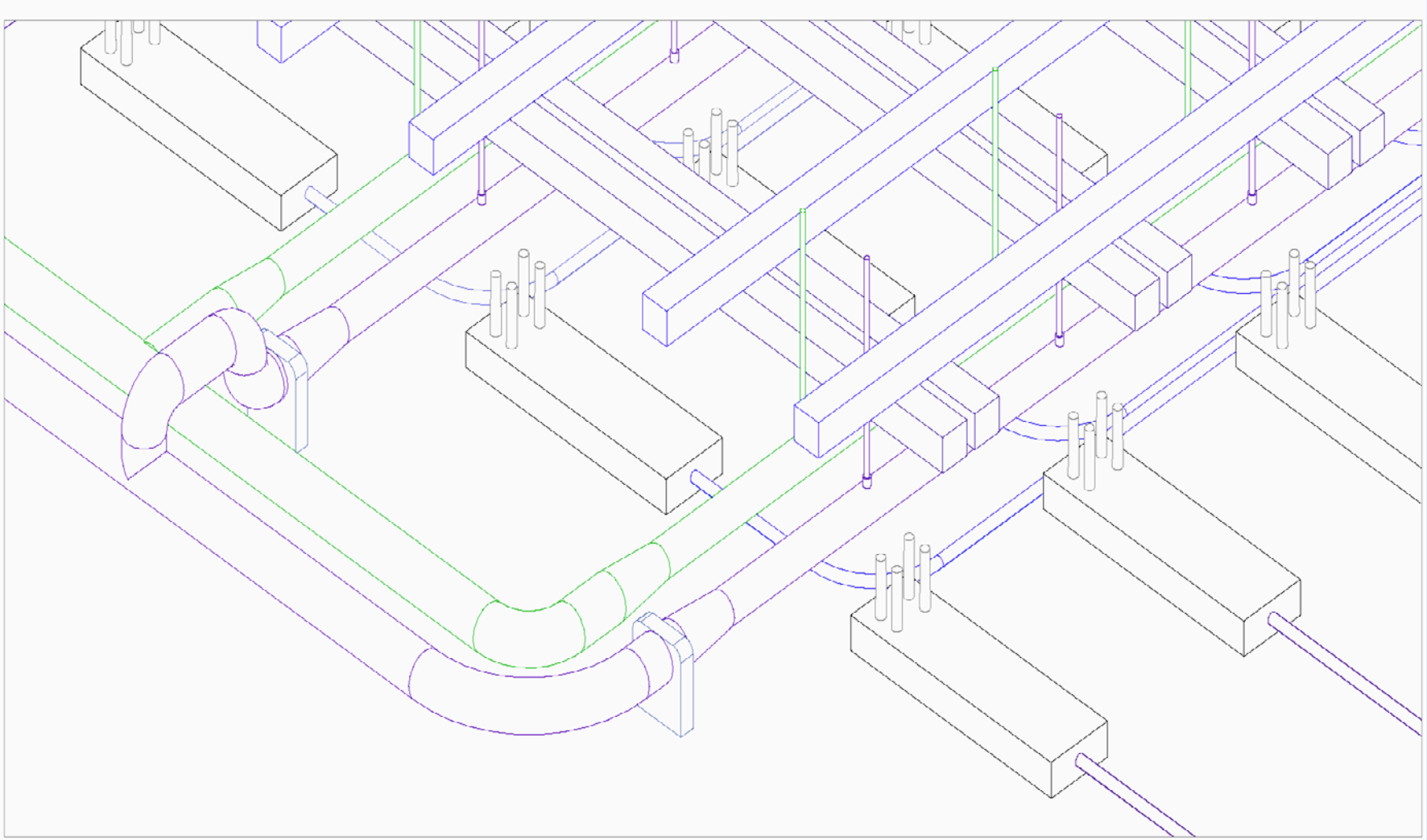
- **Stainless or copping piping required from strainers to the racks – Locate strainers close to racks to minimize costs**
- **Strict water quality issues to ensure rack level components are not compromised**

Locally designed under rack power cord consolidation saves significant installation costs and increases facility efficiency

Sequoia Facilities System Layout – Profile View



Sequoia Facilities System Layout – Under Floor Isometric



Questions

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