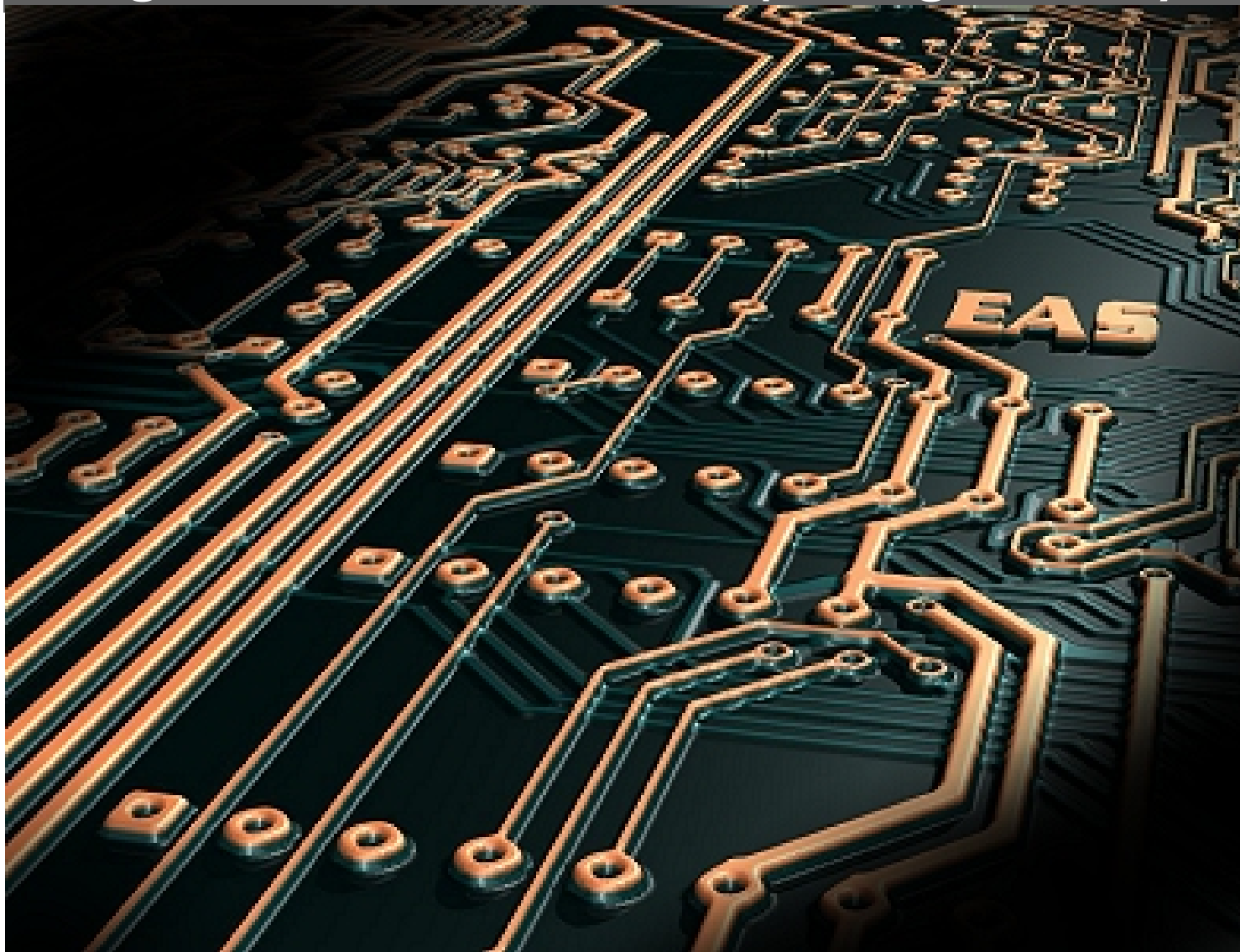
Designing a Flexible, Energy Efficient High Performance Computing Facility



HELLMUTH, OBATA + KASSABAUM

- 25 Offices Worldwide
  Over 1,800 Professionals
- #1 Architectural/Engineering Firm,
  Building Design + Construction, 2010
- #1 Architectural/Engineering Firm,
  Engineering News-Record, 2010
- Award Winning Design
  40 – State, National and International Design Awards in Last 5 Years
- Sustainable Design Leadership
  Over 850 LEED AP Personnel
- Market Focus, S + T, Mission Critical
- Integrated Design Practice
  A/IA/MEP/S
- BIM Savvy

OFFICE LOCATIONS

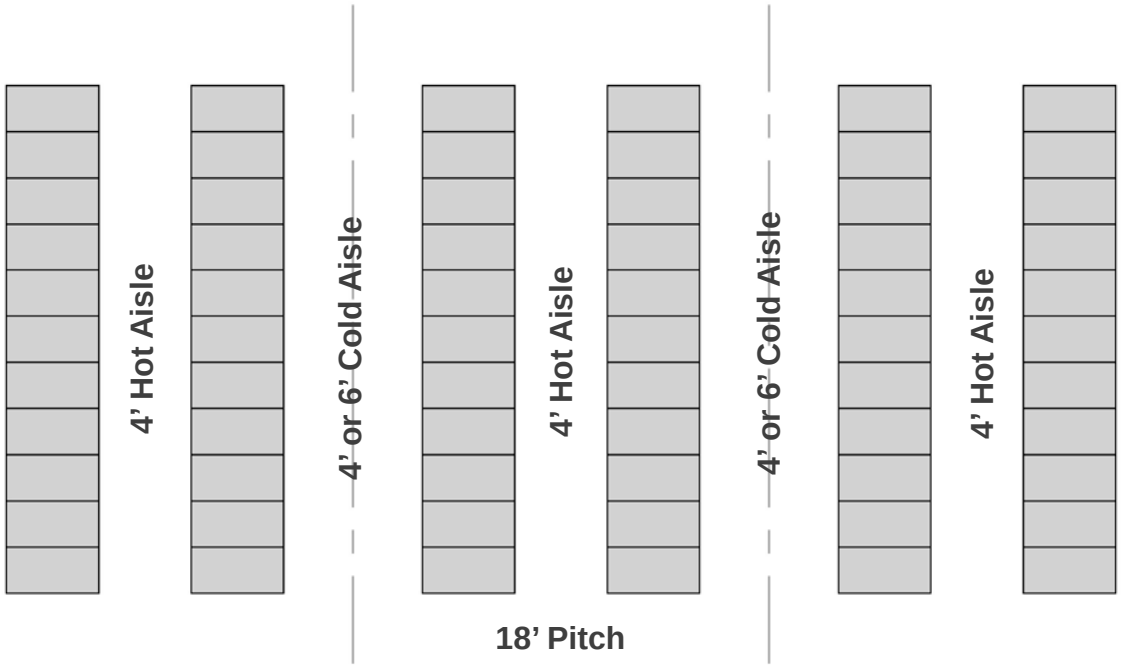
25 OFFICES THOUGHOUT THE AMERICAS, CANADA, EUROPE AND THE FAR EAST

OWNER STATEMENT OF REQUIREMENTS

- Design High Performance Computing Facility with Ultimate 15 MVA Electrical Service
- Target PUE of 1.35 Average, 1.5 Maximum
- Space for 400 Standard, 2'x4'x48u Racks with 300 Operational
- Hot and Cold Aisles
- Internal Growth Capacity and Flexibility, Futureproof
- Scalable-Gradual Build to Ultimate Capacity
- Maximum 35 KW Power Usage per Rack
- 36 inch High Underfloor Plenum
- N+1 Cooling Equipment Redundancy, 2N UPS Redundancy
- Physically Protected White Space
- Office Space for up to 45 Workstations

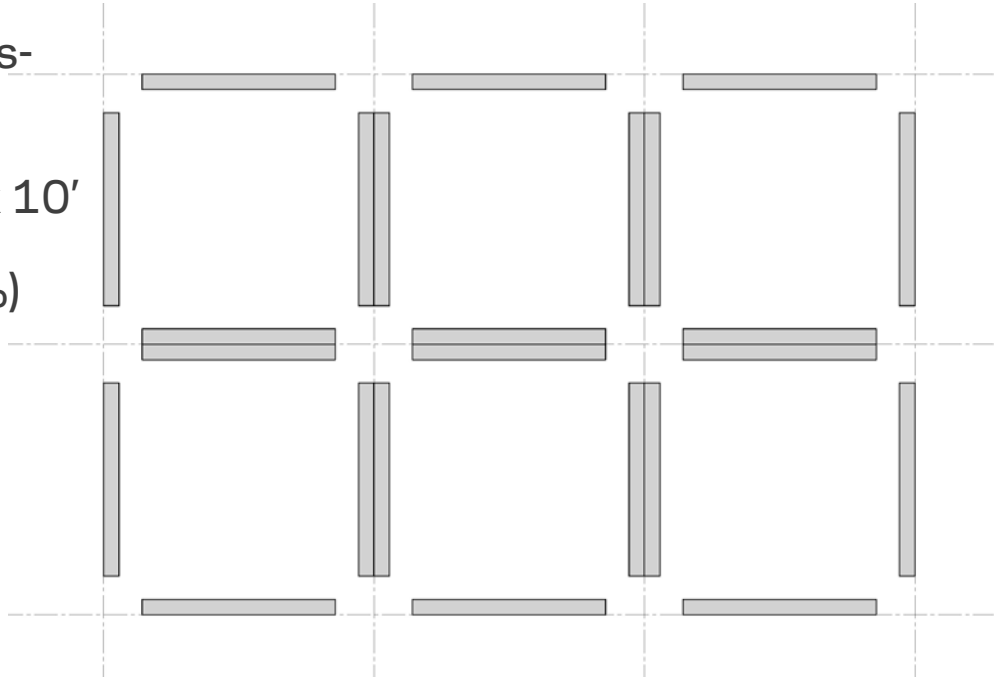
RACK LAYOUT PARAMETERS

- **Rack Layout**
  - Rack Dimensions 2′ W x 4′ D
  - Hot Aisle 4′ for Tenant 1, 4′ for Tenant 2
  - Cold Aisle 6′ for Tenant 1, 4′ for Tenant 2

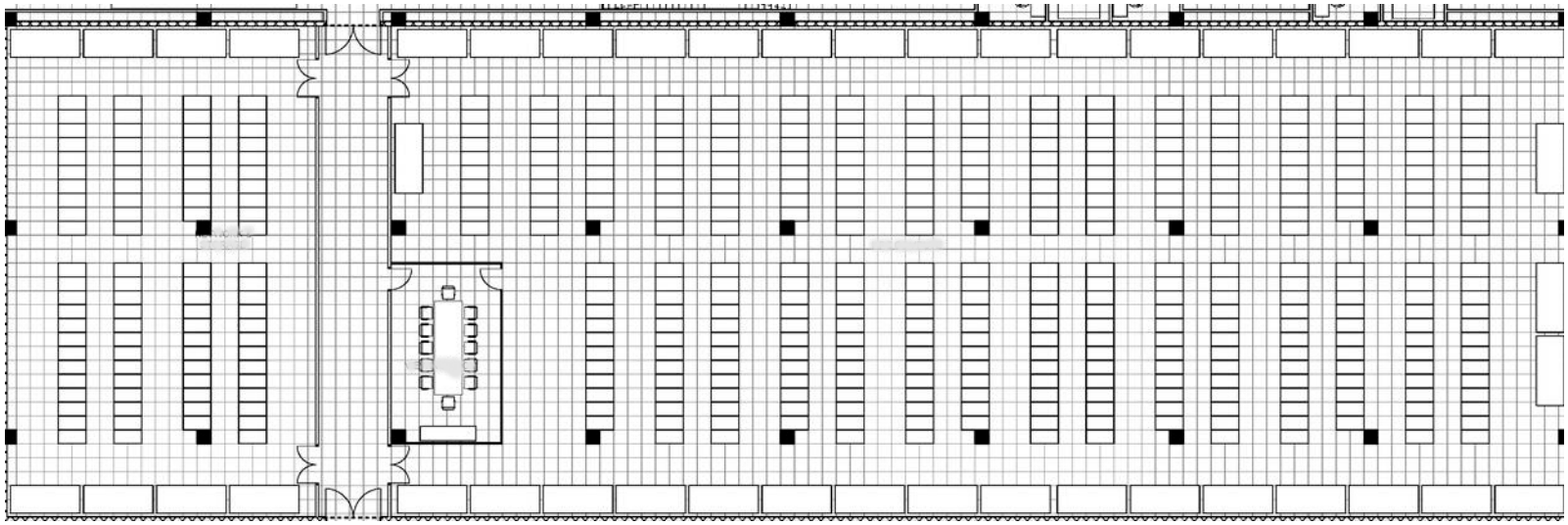


COMPUTING SPACE PARAMETERS

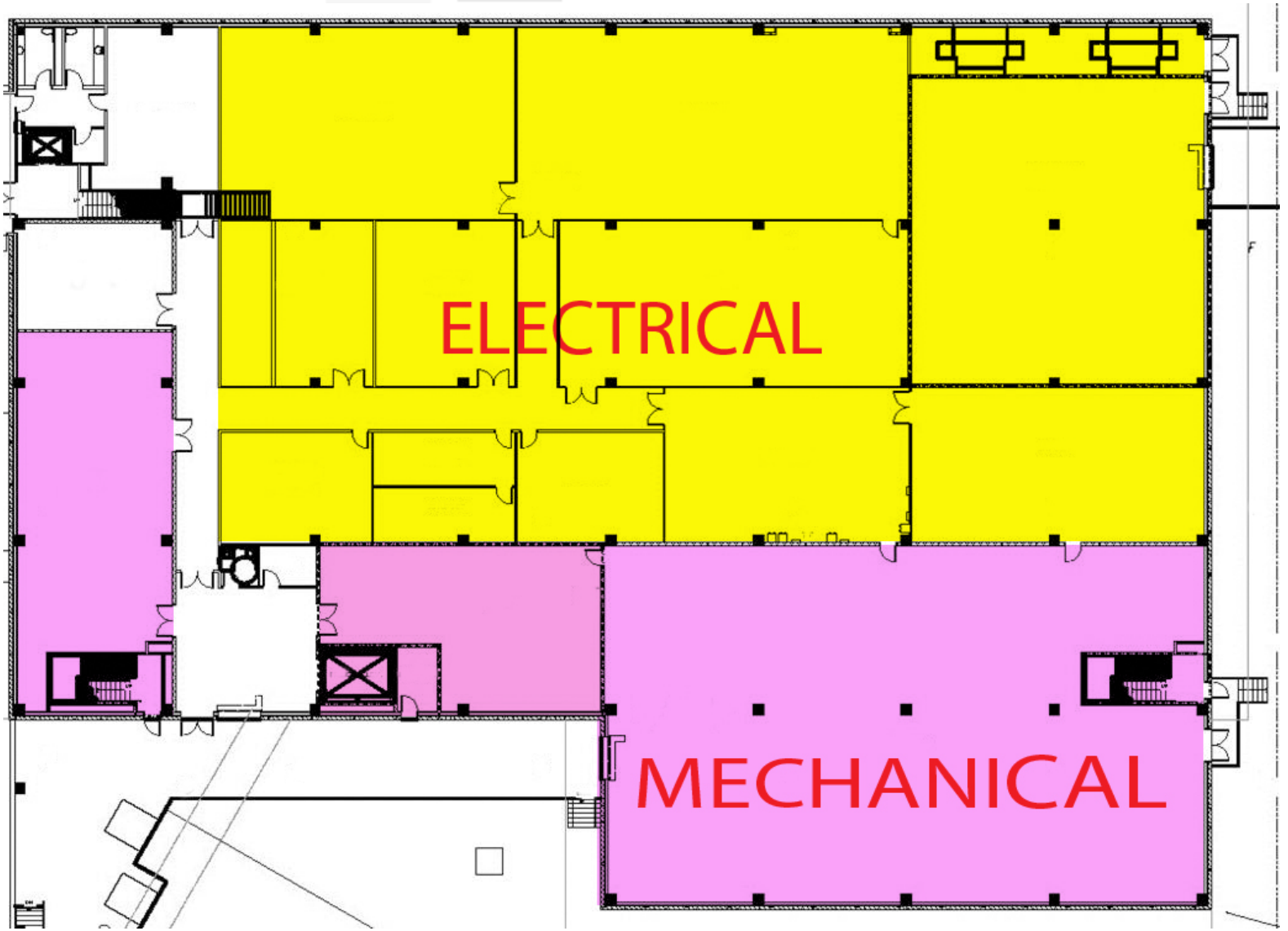
- Supply Air from Underfloor Plenum
- Return Air from Ceiling Plenum
- CRAC Unit Air Distribution Radius-35′
- 50 Ton CRAC Unit Footprint-4′ x 10′
- CRAC Unit Redundancy (N+25%)
- Power/Data Distribution From Underfloor Plenum
- Limit Use of PDUs



WHITE SPACE LAYOUT-TENANT 1

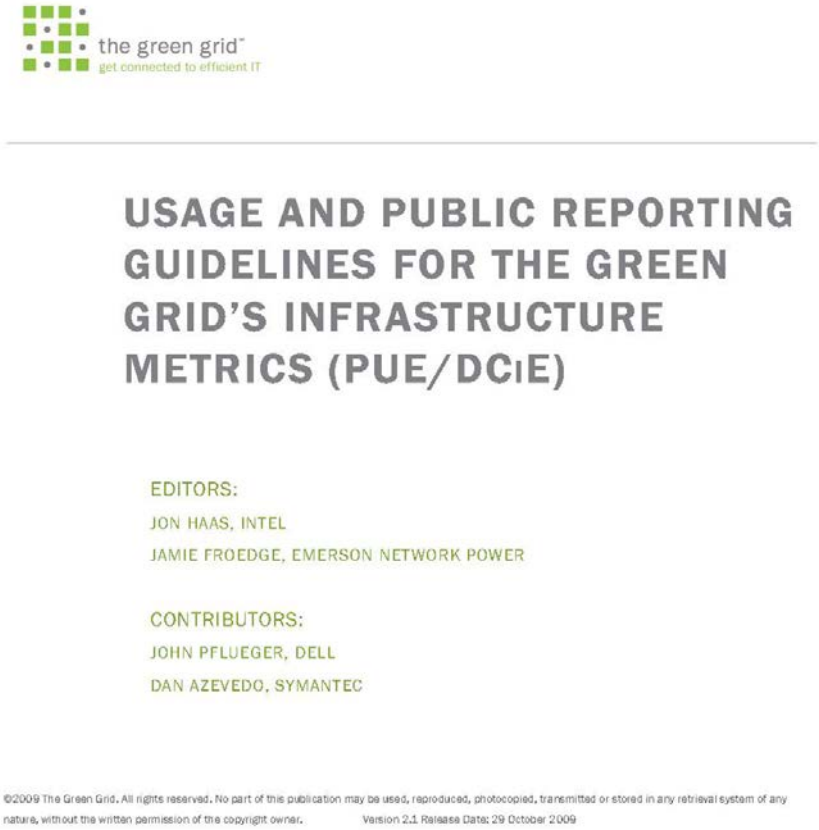


MEP INFRASTRUCTURE



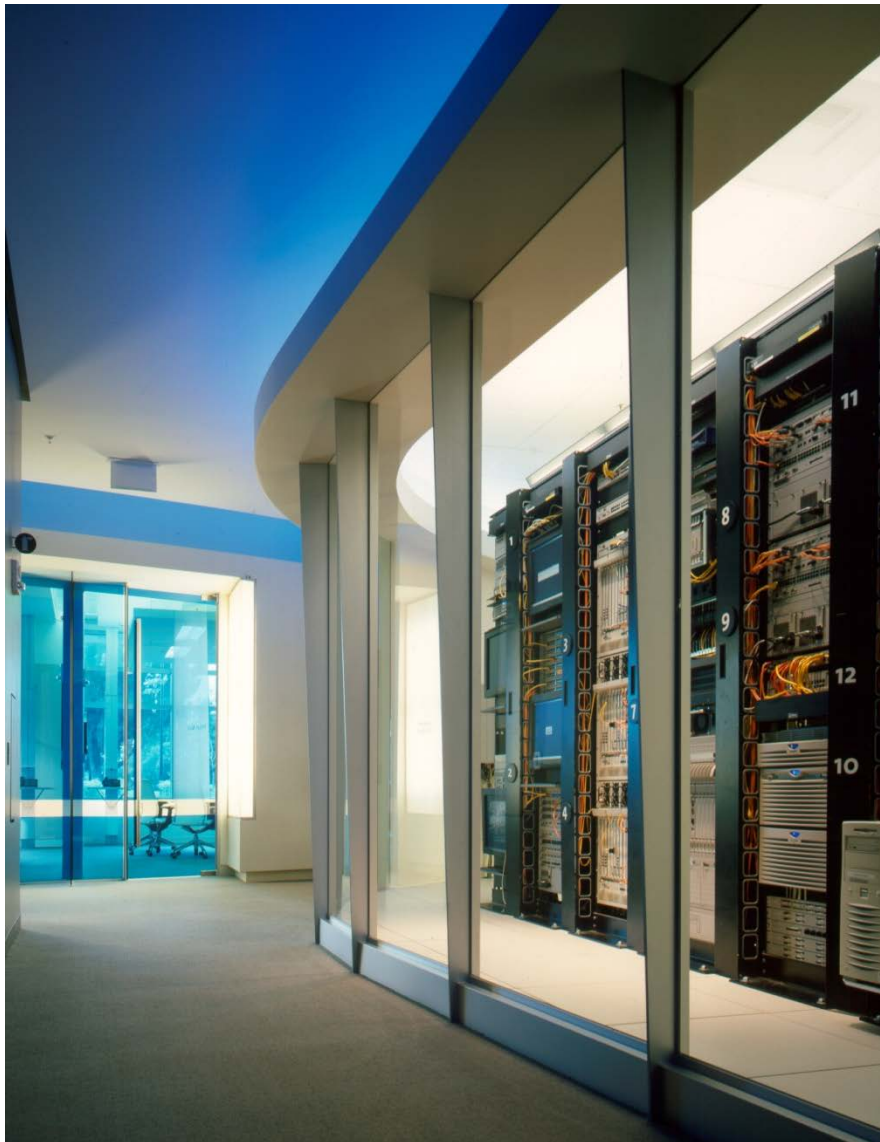
PUE ASPIRATION

- Annual Average PUE of 1.35, Maximum of 1.5
  - Aggressive, but Attainable
  - Regional Benchmarking
  - Limitations of Current Technology
  - Life Cycle Cost Justified
  - Small Change Amplified by 24/7 Operation (8,760 hours per year)



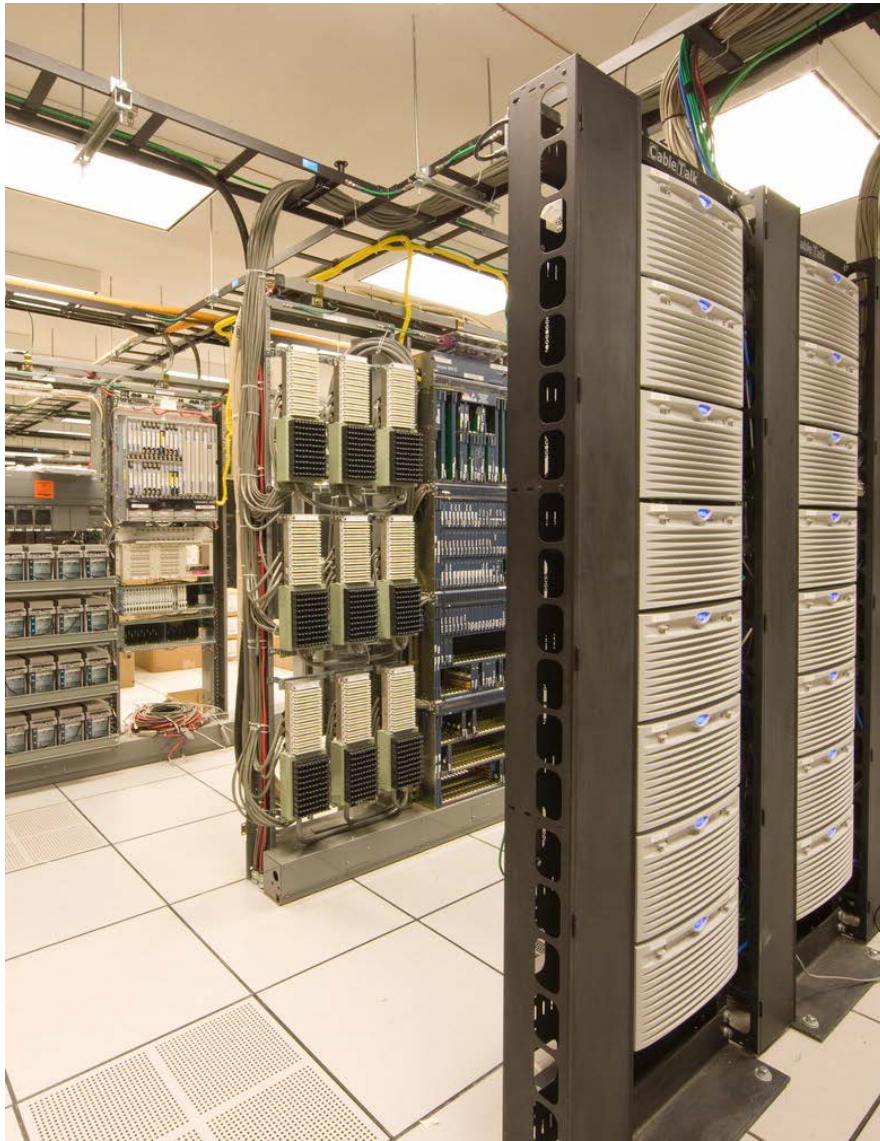
CALCULATED PUE TENANT 1

- Design – 1.33
  - IT: 1.00
  - Cooling: 0.24
  - Equipment Losses: 0.08
  - Lighting: 0.01
- Annual Average – 1.31
  - IT: 1.00
  - Cooling: 0.21
  - Equipment Losses: 0.09
  - Lighting: 0.01



CALCULATED PUE TENANT 2

- Design – 1.64
  - IT: 1.00
  - Cooling: 0.42
  - Equipment Losses: 0.13
  - Lighting: 0.09
- Annual Average – 1.45
  - IT: 1.00
  - Cooling: 0.28
  - Equipment Losses: 0.11
  - Lighting: 0.06

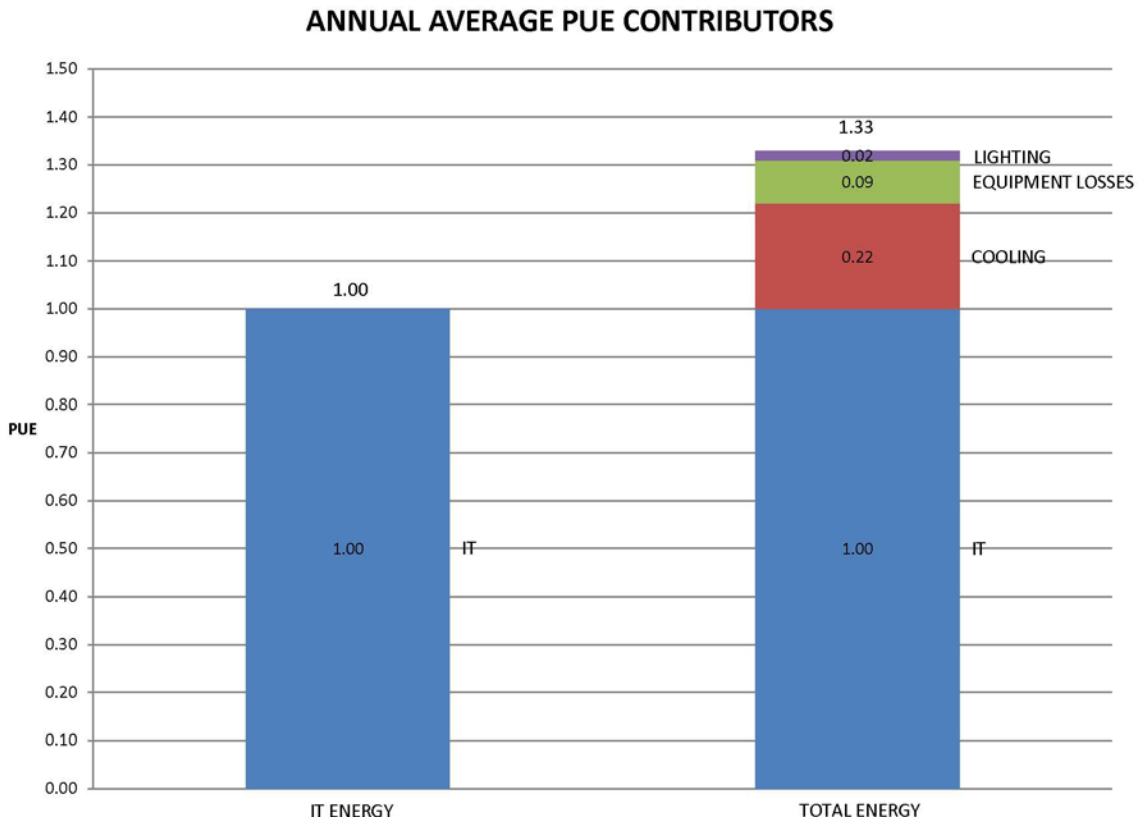


CALCULATED PUE TOTAL

- Design – 1.38
  - IT: 1.00
  - Cooling: 0.27
  - Equipment Losses: 0.09
  - Lighting: 0.02
- Annual Average – 1.33
  - IT: 1.00
  - Cooling: 0.22
  - Equipment Losses: 0.09
  - Lighting: 0.02

IMPACT OF COOLING ON PUE

- Cooling has Large Impact to PUE (67 % of Non-IT)
- To Improve…Need to First Understand What Impacts Cooling and Associated Power and Energy Consumption
- **Conclusion:** Incremental Reduction to Cooling Energy has Big Impact

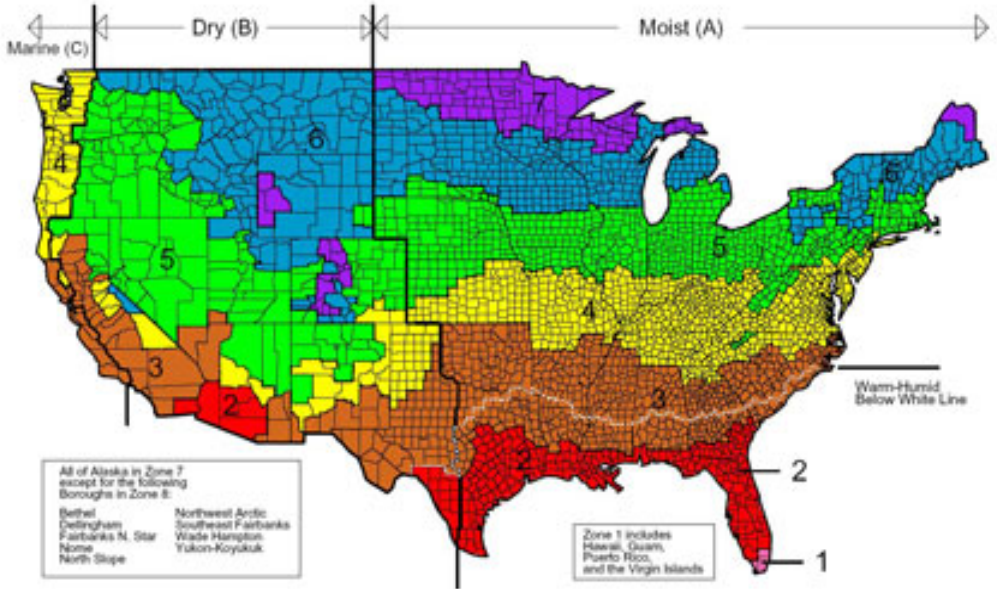


IMPACT OF CLIMATE ON COOLING LOADS

- Process: None
- Building Envelope:
  - Function of Mass and Thermal Properties, Orientation, Fenestration, Shading and Dry Bulb Temperature
  - Can be Significant if not Properly Addressed
  - Small Compared to Process Load
- Outdoor Air:
  - Significant in Houston Climate Due to Extreme Coincident Temperature and Humidity
  - Computing Facilities have Minimal Amount Required for Occupant Ventilation and Positive Pressurization
  - Small Compared to Process Load
- **Conclusion:** Biggest Portion of Total Cooling Load in Computing Facility (Process Load) is not Impacted by Climate

IMPACT OF CLIMATE ON COOLING SYSTEM ENERGY USAGE

- **Cooling system means of heat rejection to outdoors**
  - Sensible Only
  - Evaporative Cooling
- **Cold versus hot climates**
  - Cold Climates Better for Cooling
  - Equipment More Energy Efficient
  - Greater Opportunity for Economizers
- **Arid versus humid climates**
  - Arid Climates Better for Evaporative Cooling



IMPACT OF CLIMATE ON COOLING
SYSTEM ENERGY USAGE

- Houston Climate Ranks Among Worst US Cities for Cooling
- Houston Waterside Economizer Cooling Hours-Chillers Off
  - 44 degree F chilled water supply: 379 hours
  - 55 degree F chilled water supply: 1229 hours
  - 60 degree F chilled water supply: 2010 hours
  - 65 degree F chilled water supply: 2907 hours
- **Conclusion:** Houston Climate is not Cooling Friendly…Make the Most of It

Houston, TX Climate Data

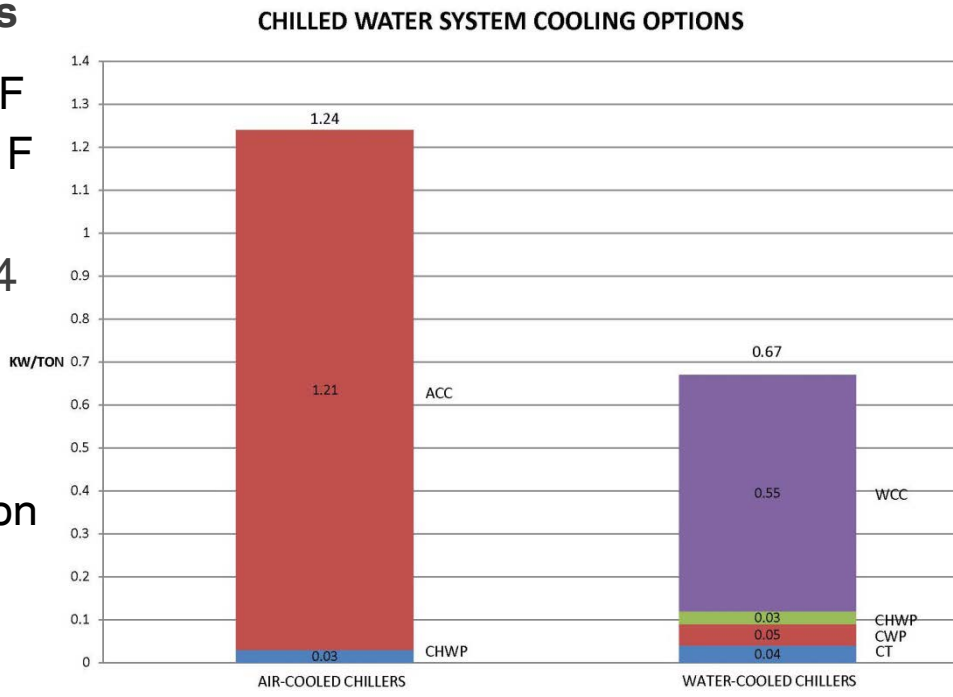
			Wet Bulb Range																	
Dry Bulb Range			0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
(°F)	to	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)
10	to	15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	to	20	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	to	25	0	0	0	6	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	to	30	0	0	0	1	20	36	0	0	0	0	0	0	0	0	0	0	0	0	0
30	to	35	0	0	0	0	9	38	115	0	0	0	0	0	0	0	0	0	0	0	0
35	to	40	0	0	0	0	0	8	115	182	0	0	0	0	0	0	0	0	0	0	0
40	to	45	0	0	0	0	0	0	19	107	155	0	0	0	0	0	0	0	0	0	0
45	to	50	0	0	0	0	0	0	4	57	155	153	0	0	0	0	0	0	0	0	0
50	to	55	0	0	0	0	0	0	0	16	91	194	176	0	0	0	0	0	0	0	0
55	to	60	0	0	0	0	0	0	0	1	58	83	217	204	0	0	0	0	0	0	0
60	to	65	0	0	0	0	0	0	0	0	15	74	90	234	448	0	0	0	0	0	0
65	to	70	0	0	0	0	0	0	0	0	0	12	30	66	289	398	0	0	0	0	0
70	to	75	0	0	0	0	0	0	0	0	0	2	27	73	144	715	471	0	0	0	0
75	to	80	0	0	0	0	0	0	0	0	0	0	4	37	87	279	822	249	0	0	0
80	to	85	0	0	0	0	0	0	0	0	0	0	0	2	38	192	407	474	1	0	0
85	to	90	0	0	0	0	0	0	0	0	0	0	0	0	0	16	143	336	19	0	0
90	to	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	264	9	0	0
95	to	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0
100	to	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Year Total Bin Hours at WB:			0	0	6	12	39	82	253	363	474	518	544	616	1006	1600	1877	1341	29	0	0
Percent of Total Hours:			0%	0%	0%	0%	0%	1%	3%	4%	5%	6%	6%	7%	11%	18%	21%	15%	0%	0%	0%
Year Total Hours (below WB):			0	0	6	18	57	139	392	755	1229	1747	2291	2907	3913	5513	7390	8731	8760	8760	8760
Percent of Total Hours:			0%	0%	0%	0%	1%	2%	4%	9%	14%	20%	26%	33%	45%	63%	84%	100%	100%	100%	100%

CHILLER OPTIONS AND ASSOCIATED ENERGY IMPACT

- **Air-Cooled Chillers**
  - Reject Heat to Outdoors at Temperature Above Ambient Dry Bulb Temperature
- **Water-Cooled Chillers**
  - Reject Heat to Outdoors at Temperature Above Ambient Wet Bulb Temperature
  - Wet Bulb Temperature Includes Moisture Content in Air and is Normally Lower than Dry Bulb Temperature
  - Rejecting Heat to Lower Ambient Temperature Requires Less Work by Chiller Compressor(s) and Results in Less Energy Consumption

CHILLER OPTIONS AND ASSOCIATED ENERGY IMPACT

- **Houston Outdoor Design Conditions**
  - Dry Bulb Temperature: 97 degrees F
  - Wet Bulb Temperature: 80 degrees F
  - Difference: 17 degree F
- Energy Consumption Comparison-44 Degree F Chilled Water Supply Temperature
  - High-Efficiency Water-Cooled Chillers: Consume 0.55 kilowatts/ton
  - High-Efficiency Air-Cooled Chillers: Consume 1.21 kilowatts per ton
  - Water-Cooled Chillers Result in System Savings of 0.5 to 0.6 kilowatts/ton (44-46 percent)
- **Conclusion:** Water-Cooled Chiller is Better Choice for Lower Energy



WATER-COOLED CHILLED WATER SUPPLY SYSTEM TEMPERATURE IMPACT ON ENERGY

- **55 degree F**
  - Annual: 0.42 kilowatts/ton
  - Design: 0.54 kilowatts/ton
- **44 degree F:**
  - Annual: 0.49 kilowatts/ton
  - Design: 0.70 kilowatts/ton
- **55 vs. 44 degree F:**
  - Annual: 0.07 kilowatts/ton-14 Percent Reduction
  - Design: 0.16 kilowatts/ton-23 Percent Reduction
- **Conclusion:** Higher Chilled Water Supply Temperature is Better Choice for Lower Energy

AIR AND ROOM TEMPERATURE IMPACT ON COOLING ENERGY

SUPPLY AIR 72 DEGREE F – Tenant 1

- **Total**: **0.64** kilowatts power required/ton of cooling
- **CRAC Units:** 0.10 kilowatts power required/ton of cooling
- **Chilled Water System:** **0.54** kilowatts power required/ton of cooling
  - **Chillers:** **0.42** kilowatts power required/ton of cooling
  - **Chilled Water Pumps:** 0.03 kilowatts power required/ton of cooling
  - **Condenser Water Pumps:** 0.05 kilowatts power required/ton of cooling
  - **Cooling Towers:** 0.04 kilowatts power required/ton of cooling

ROOM 72 DEGREE F – Tenant 2

- **Total:** **0.80** kilowatts power required/ton of cooling
- **CRAC Units:** 0.10 kilowatts power required/ton of cooling
- **Chilled Water System:** **0.70** kilowatts power required/ton of cooling
  - **Chillers:** **0.58** kilowatts power required/ton of cooling
  - **Chilled Water Pumps:** 0.03 kilowatts power required/ton of cooling
  - **Condenser Water Pumps:** 0.05 kilowatts power required/ton of cooling
  - **Cooling Towers:** 0.04 kilowatts power required/ton of cooling

- **Conclusion:** Higher Room and Supply Temperature is Better Choice for Lower Energy

IMPROVING WHITE SPACE COOLING ENERGY EFFICIENCY

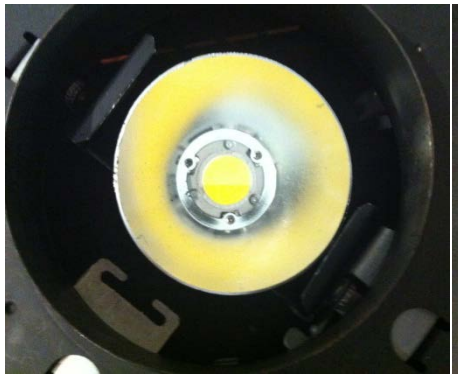
- **Increase Temperature**
  - Elevate Air And Water System Temperatures Within ASHRAE Recommended Boundaries
  - Hot-Aisle Containment
- **Reduce Pressure Loss**
  - High Airflow Capacity with Low Pressure Drop Floor Grilles
  - High Airflow Capacity with Low Pressure Drop Ceiling Grilles
- **System and Equipment**
  - Separate Chilled Water System for Sensible Only Loads Operating at Elevated Temperatures
  - High-Efficiency HVAC Equipment
  - Maximizing Climate to Reduce Energy-Use Waterside Economizer
  - Energy Recovery Before Rejecting
  - Energy Optimization Control Routines
  - Pumps And Fan Affinity Laws…Horsepower Varies to Cube of Speed
  - Variable Speed Everything (Chillers, Pumps, Fans)
  - CRAC Units with Direct Drive Variable Speed Fans (EC) Located Underfloor
- **Measurement and Verification**
  - Sub-Meter Cooling Usage
  - Sub-Meter Electric Power Usage
  - Benchmark Results
- **Conclusion:** Life Cycle Cost Effective Practices Resulting in Lower Energy and PUE

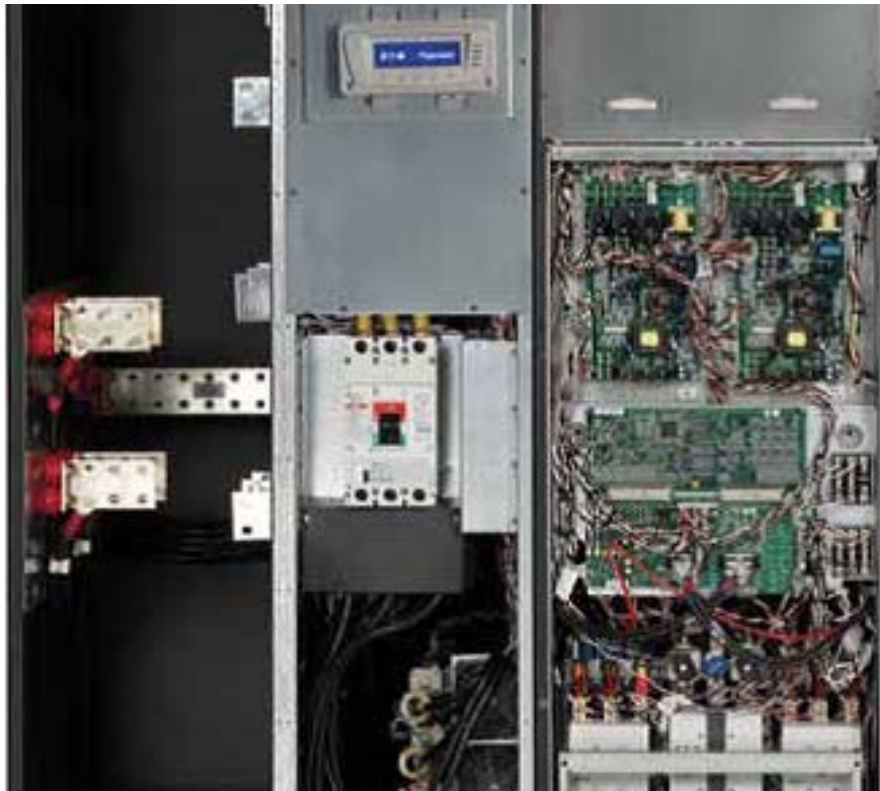
DELIVERING LONG TERM RESULTS

- Measure, Record and Process Variables Contributing to Energy Use…Temperature, Flow, Energy Delivered, Energy Consumed
- Realtime Calculations and Display
- Historical Data Collection and Reporting, Hourly, Daily, Weekly, Monthly, Annual and Since Installed
- Regular Benchmarking Against Design and New Technologies
- Regular Assessment, and Exploring of New Options While Implementing Only Cost Effective Strategies to Reduce Energy - *Effective Energy Management*

ELECTRICAL SYSTEM ENERGY SAVING STRATEGIES

- **High Efficiency Lighting**
  - LED
  - T5 and T5HO Fluorescent Lamps w/ Electronic Ballasts
  - Automated Controls
- **Equipment**
  - High-Efficiency Transformers
  - UPS Energy Saver Mode
  - Rack Power – Building Utilization Voltage



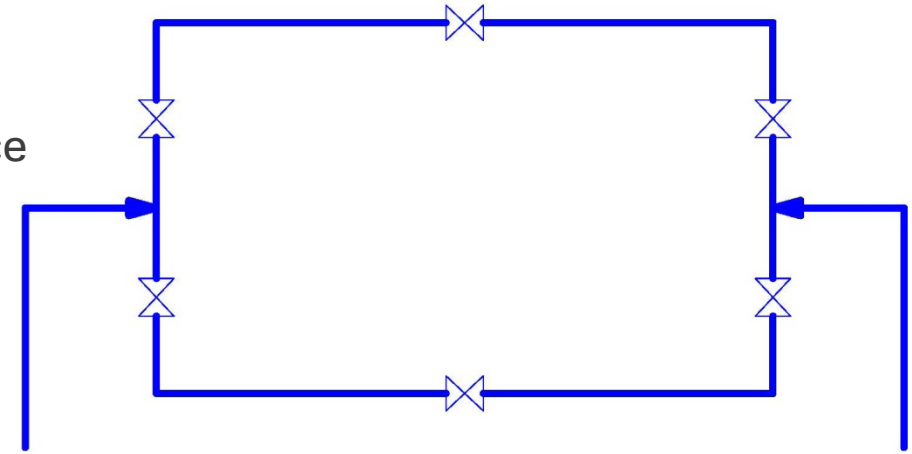


ELECTRICAL SYSTEM ADAPTABILITY

- Infrastructure to Support Ultimate Loads
- Equipment Added to Support Demand
- Planned and Managed Underfloor Plenum Cable Distribution
- Designed to Support Alternative Energy Source

DESIGNING WHITE SPACE COOLING FOR CHANGE

- Modular Cooling Design to Support Load and Environmental Changes
  - Partition Provisions
  - Equipment Provisions
  - Cooling System Provisions-multiple systems operating at different temperatures
- Cool with Air, Liquid or Both
- Capture Heat and Cool Close to Source as Practical
  - Containment
  - More Effective Cooling Resulting in Improved Energy Efficiency
  - Improved Reliability
- Build Infrastructure to Support Change
  - Dual Fed Loop Pipe Distribution with Sectionalizing Valves
  - Operating Redundant Equipment



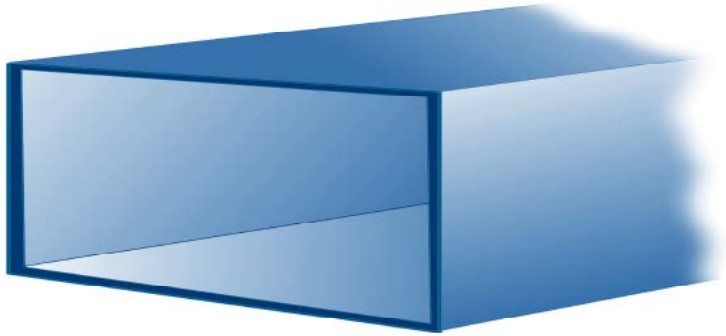
LIQUID vs. AIR COOLING IN WHITE SPACE

- **Physical Limitations to Cool with Air**
  - Space for CRAC units
  - Pressurized Underfloor Plenum Depth
  - Ceiling Plenum Depth
  - Space and Arrangement of Floor and Ceiling Air Grilles
  - Transporting equal cooling in pipe is hundreds of times less space than duct
- **Energy Limitations to Cooling with Air**
  - Trend to Lower PUE
  - Water (or similar liquid) much more efficient than air

Flow Cross Section

18“ x 18“

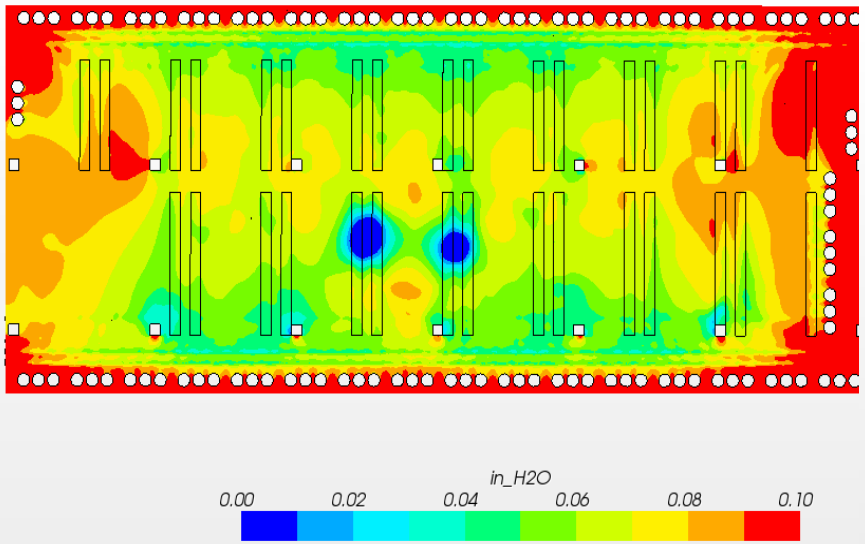
Air Duct

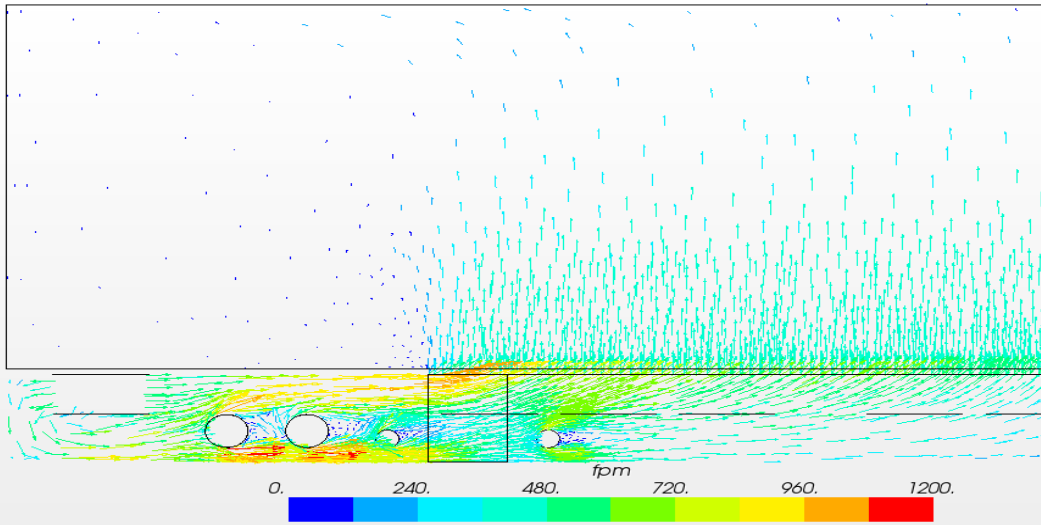


1“ diameter Water Pipe

LIQUID vs. AIR COOLING IN WHITE SPACE

- **Trend Toward Increased Heat Density**
  - Initial Project Requirement of 35 kilowatts per Rack
  - 6 months Later Requirement being Challenged (40+ kilowatts per Rack)
- **Advances in Liquid Technology**
  - Cooled Rack Enclosures
  - Cold Plates
  - Liquid-Cooled Processors
- **Conclusion:** Liquid Cooling is Preferred Over Air in High Heat Density Applications …so…Develop a Design to Accommodate Both





THANK YOU

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