The Basic Economics of Heat Recovery in Labs

Laboratories for the 21st Century Conference *September 2000*

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Basic Issues

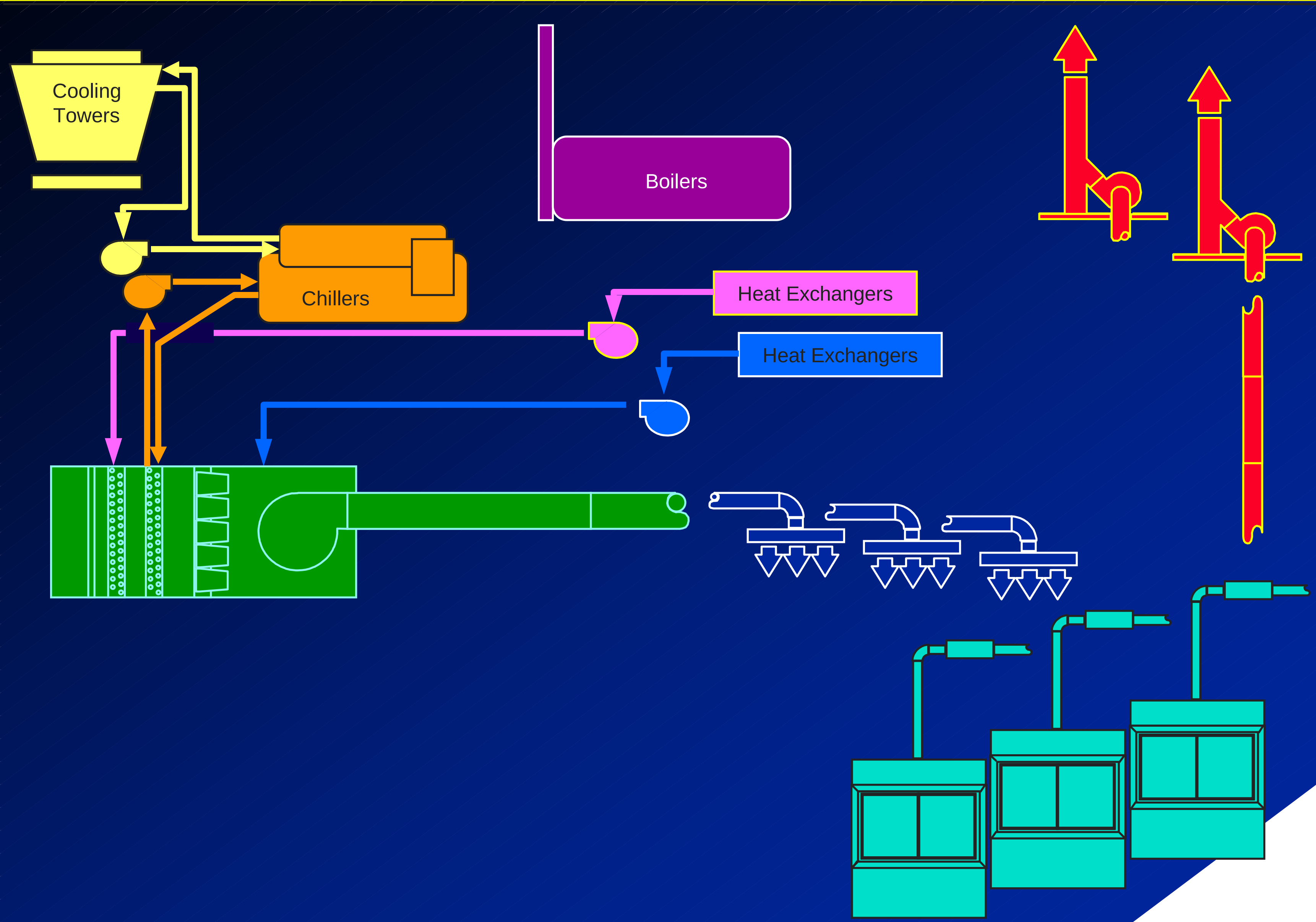
Energy in Laboratories … Implications of 100% Outside Air!

Waste Energy … Once-thru Mentality!

Recovery Opportunities

- Water vs. Air Systems
- Process vs. Comfort Systems
- Total Heat vs. Sensible Heat

Basic HVAC Systems … Energy Use



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Origin of Energy Use and Costs

Fume Hoods are the Energy Hogs of Labs … but Airflows for Cooling Load Can Also Be a Major Factor

Exhaust Airflow Is the Most Promising Target for Energy Recovery in Most Laboratories!

Basic Issues

Energy in Laboratories

Waste Energy

Recovery Opportunities

- Process vs. Comfort Systems
- Water vs. Air Systems
- Total Heat vs. Sensible Heat

Air-to-Air Technologies

- Flat Fixed Plate Heat Exchangers
- Heat Pipe Exchangers
- Rotary (Heat Wheel) Exchangers
- Coil Recovery (Run-Around) Loops

Economics

- Energy Costs
- Maintenance Costs
- Installation (and “Deferred”) Costs
- Financial Considerations

Factors Affecting Energy Use

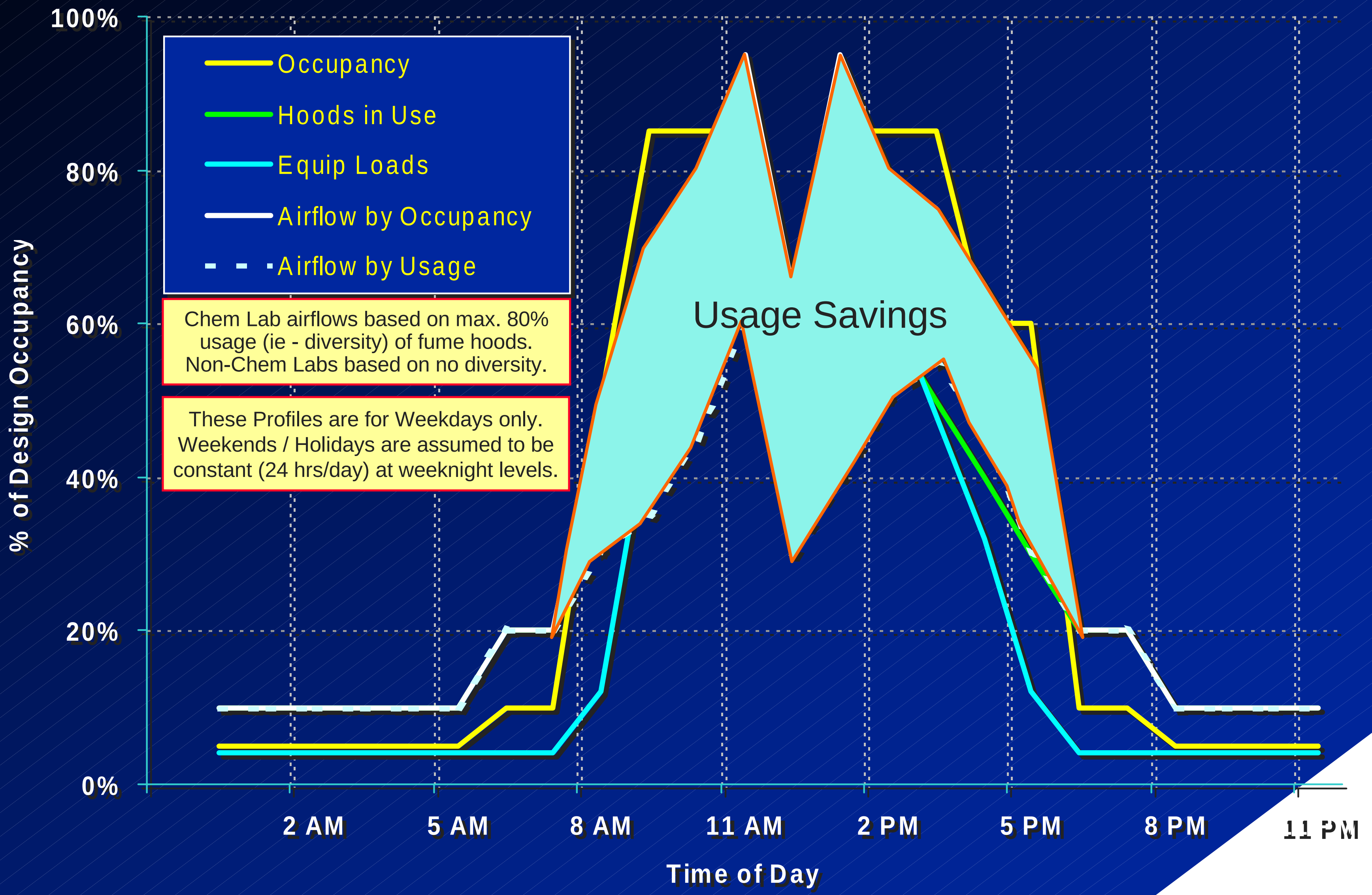
Airflow Density … Peak flow for:

- Fume Hoods (size, quantity, sash area, face velocity, diversity …)
- Loads
- Room Ventilation / Dilution

Airflow Usage

- Variable or Constant
- Operating Schedule / Operating Diversity … Controls to Capture It
  - Hourly / Daily by Lab
  - Hourly / Daily Between Labs
  - Seasonal

Typical Operational Profiles



Chem Lab airflows based on max. 80% usage (ie - diversity) of fume hoods. Non-Chem Labs based on no diversity.

These Profiles are for Weekdays only. Weekends / Holidays are assumed to be constant (24 hrs/day) at weeknight levels.

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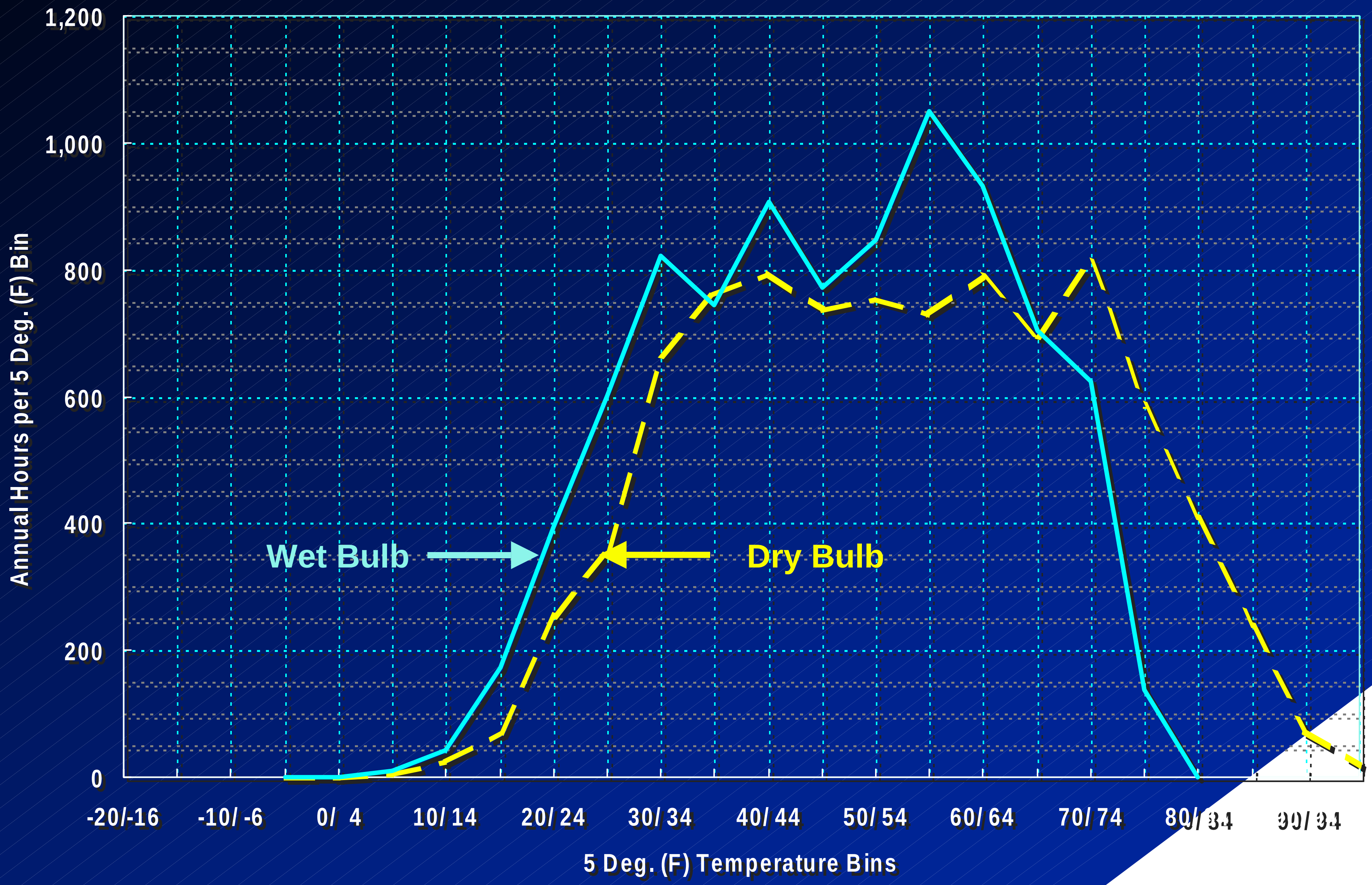
System Performance

- Capacity vs. Load … Part Load Efficiencies
- Load “Tracking”
- Static Pressure Losses
- Flow and Static Pressure Variations

Weather Impacts … Local Climate

PROFILES of TEMPERATURES in PHILADELPHIA, PA



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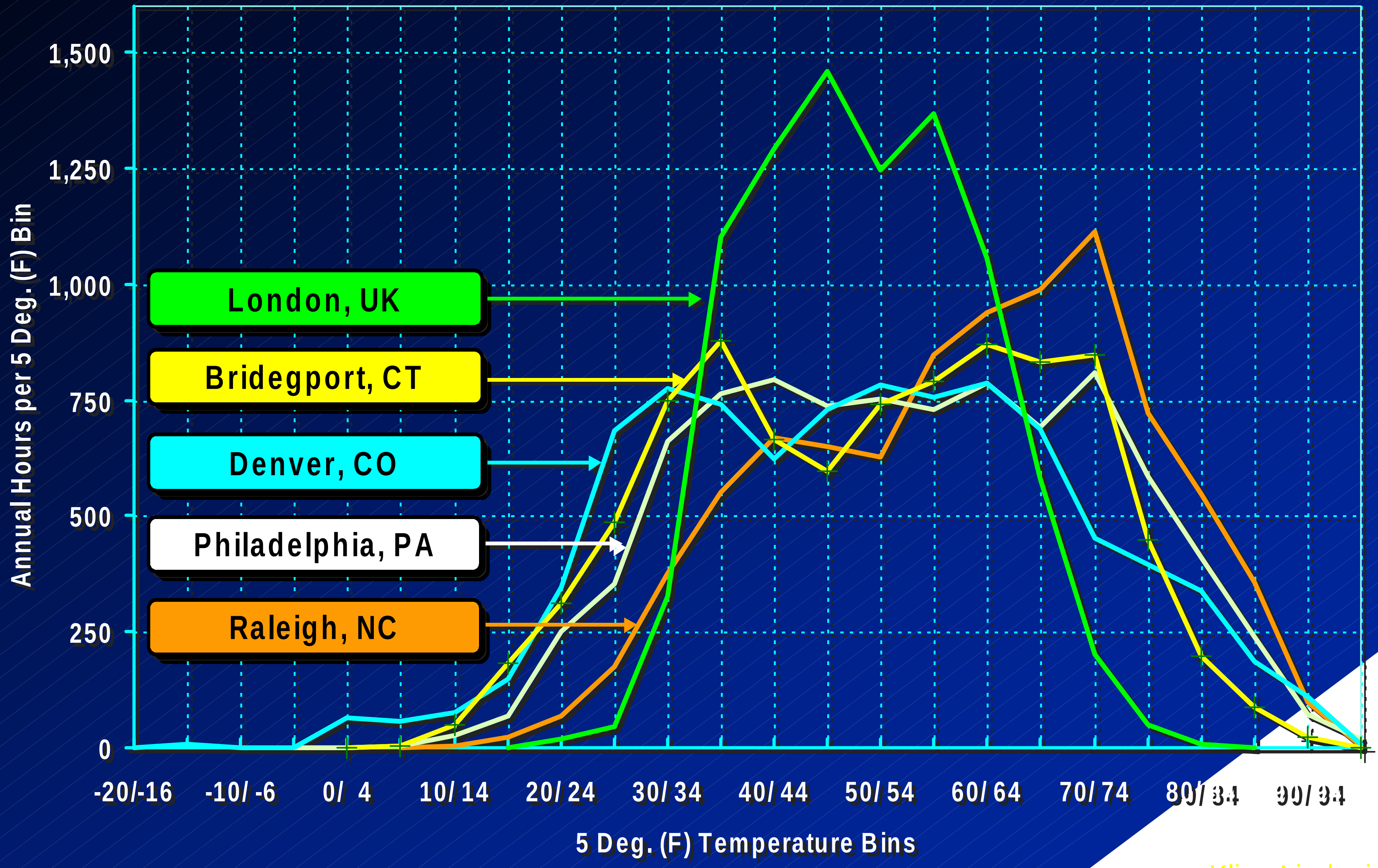
PROFILES of DRY BULB TEMPERATURES



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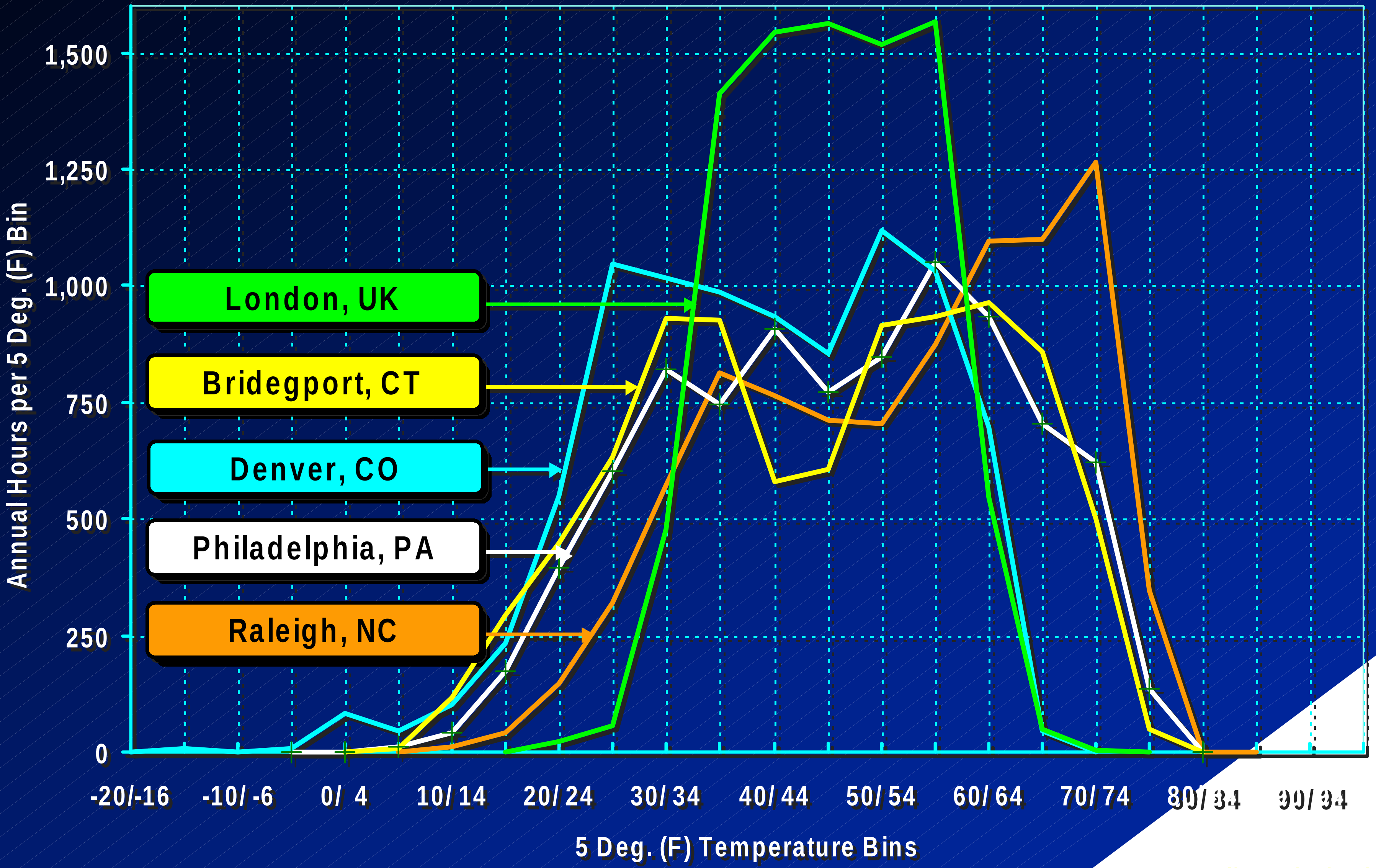
PROFILES of WET BULB TEMPERATURES



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Basic Question 1 – What are the Most Significant Determinant(s) in the (Cost) Effectiveness of an Energy Recovery Scheme?

- Avoided Energy (Consumption) Costs?
  - Electricity?
  - Thermal / Fuel Based?
- Avoided Energy (Demand) Costs?
  - Utility Demands?
- Avoided Equipment Capacity and Associated Costs?
  - Equipment First Costs?
  - Space Requirements?
  - Code / Permitting Requirements?
- Other Financial Impacts?
  - Tax Consequences?
  - Implications of Fuel Escalation?
  - Implications of Inflation?
- Maintenance Considerations?
- Sustainability Issues?
  - Environmental / Pollution Control Issues?
  - Natural Resource Considerations?

Basic Question 2 – How Accurately Can the Complex Interactions of Energy Use by Laboratory HVAC Systems be “Modeled”?

- How Many Variables are “Significant”?
    - Ambient Conditions … Supply / Space Conditions
    - Mass Flow Rates … Air and Fluids
    - Pressure Drops … Fan Efficiencies
    - Energy Cost … Energy Recovery Rate
- What Interactions do They Have and Do They Change Over Time?
- Can They All be Adequately Established?
- What Assumptions are Necessary regarding:
    - Weather?
    - Building Operation?
    - System Loads?
    - Controls?
    - Utility Rates?
    - Maintenance Considerations?
- What are the Implications to Errors in the Scale of these Variables?
- What are the Implications to Errors in their Dependency on Other Variables?
- How are the Lab Facility Growth and Other Changes Factored In?

Influence of System Efficiency on Energy Use in Labs

Equipment Concepts

- Part Load Operation of Equipment Is Especially Significant
- Peak Load Efficiencies Are Less Critical As Peaks Are Rare

Generation Concepts

- Optimization of Prime Movers for Fuel Utilization
- Optimization of Temperature Differentials to Match Load Densities, Profiles and Base Load Characteristics

Conversion Concepts

- Optimization of Temperature Differentials to Match Load Densities, Profiles and Base Load Characteristics

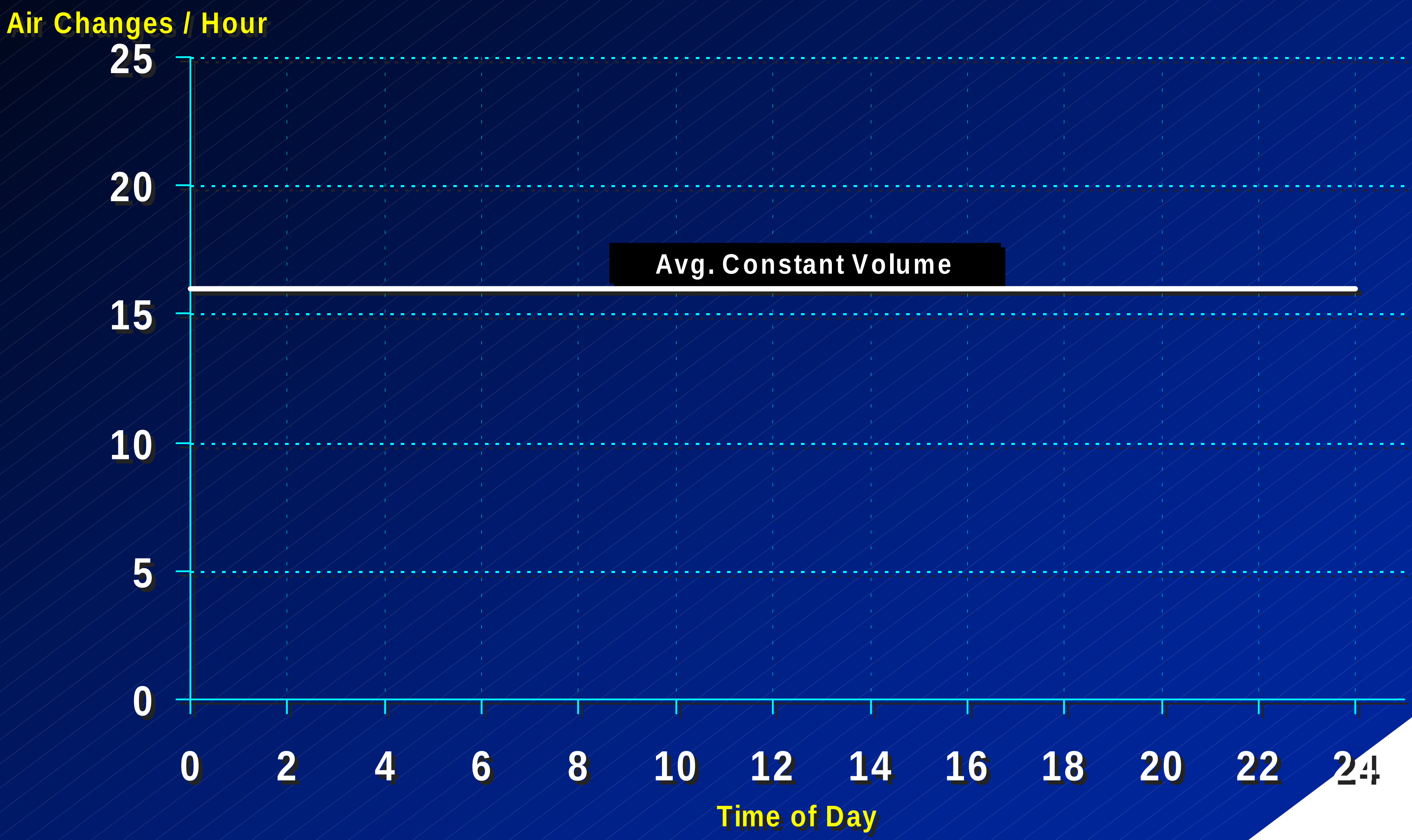
Distribution Concepts

- Optimization of Temperature Differentials to Match Load Densities and Minimize “Excessive” Losses
- Minimize Distribution Losses With Both Optimal Insulation and Good Engineering Practice to Eliminate Excessive Pressure Loss Situations in the Distribution Systems.

Influence of Dynamic Operations on Energy Use in Labs

- Diversities
    - Application of Diversities to both Equipment and Distribution systems.
    - Possible Offset of “Future” or “redundant” requirements with the “reserves” available from system “diversities.
- Recovery opportunities
    - Match available or compatible flows for both magnitude and time of day
    - Apply recovery concepts to both save Energy and Reduce “capital” expenditures. [This does risk compromising any reliability criteria.]

AIRFLOW VARIATION with CONTROL OPTIONS



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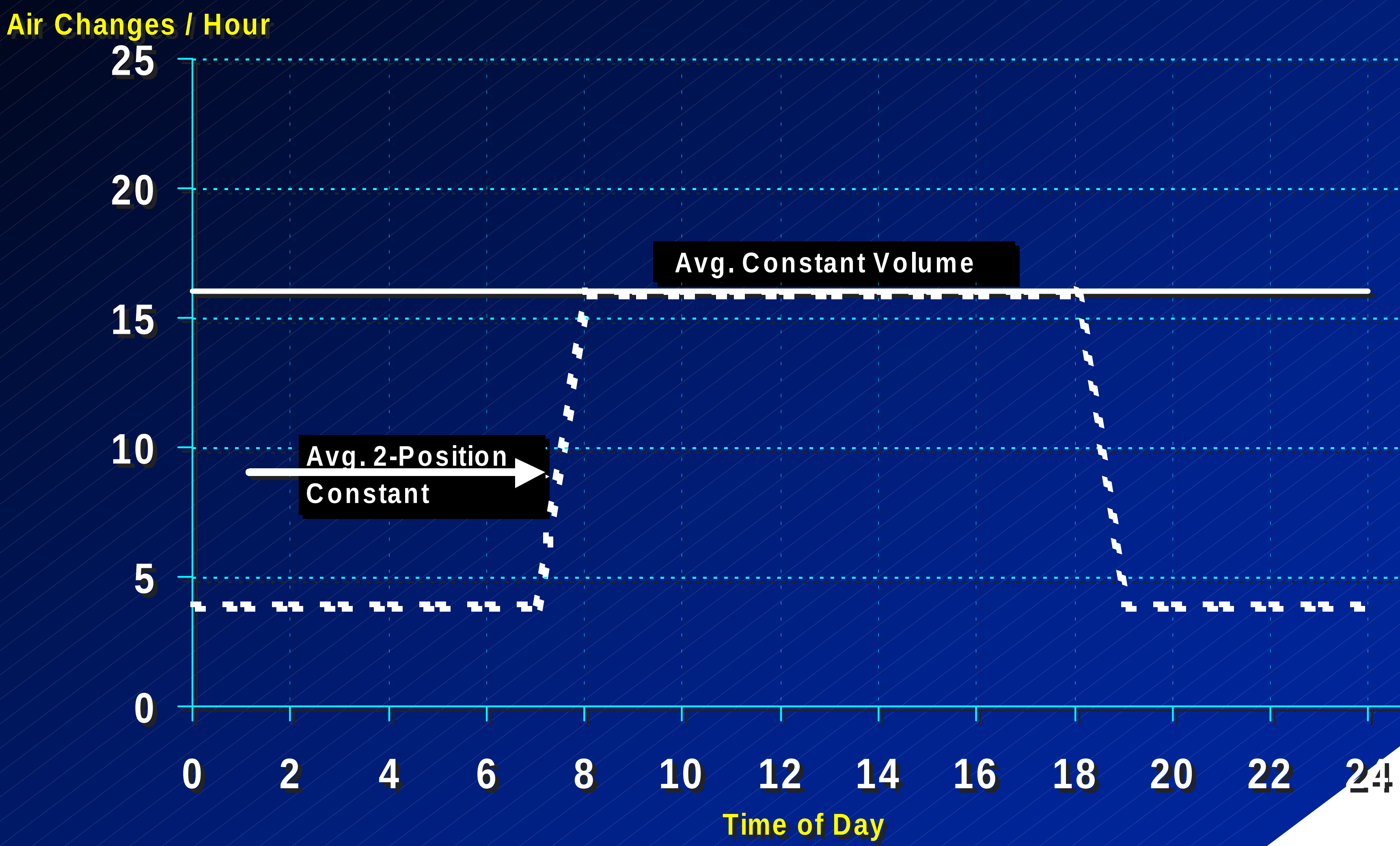

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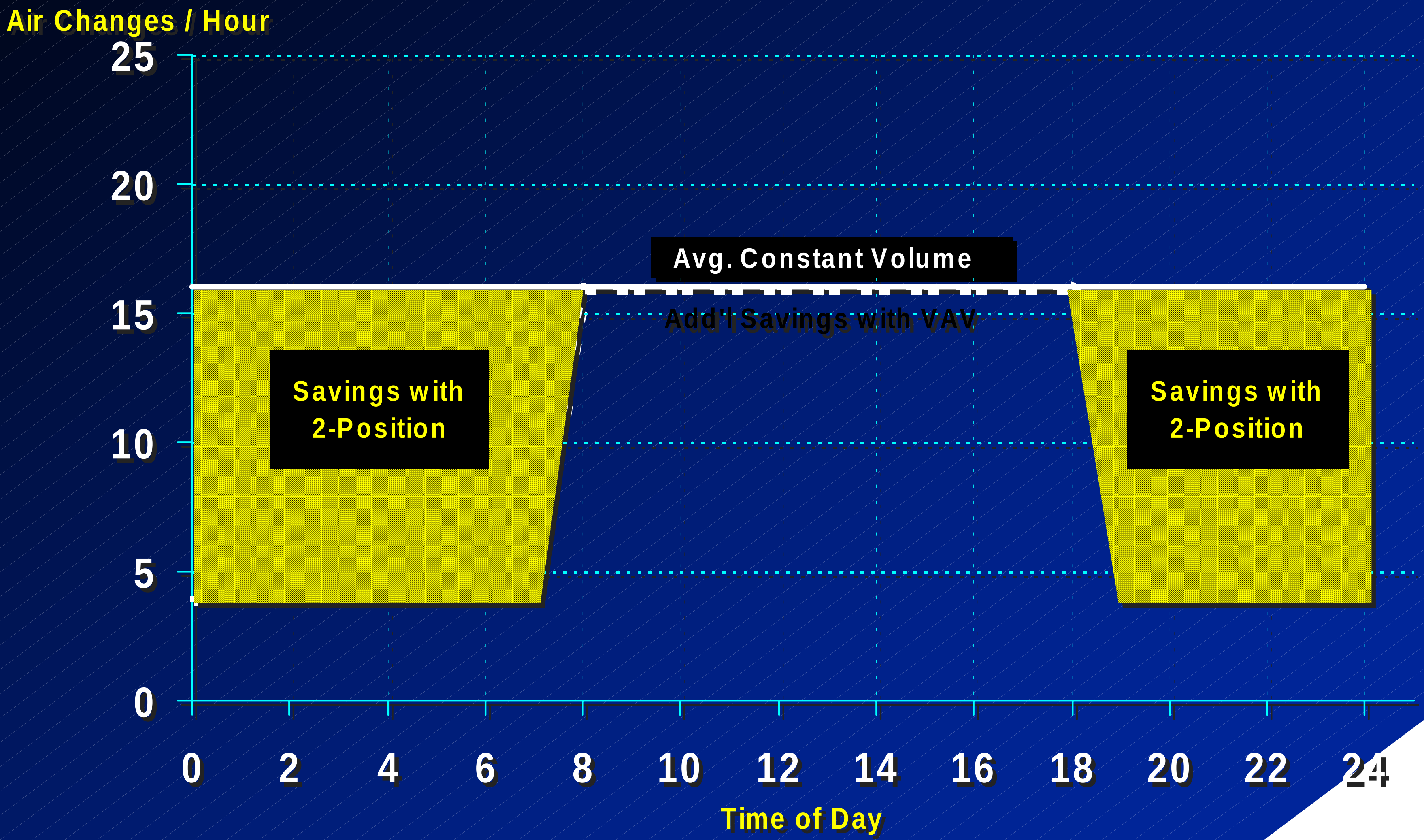

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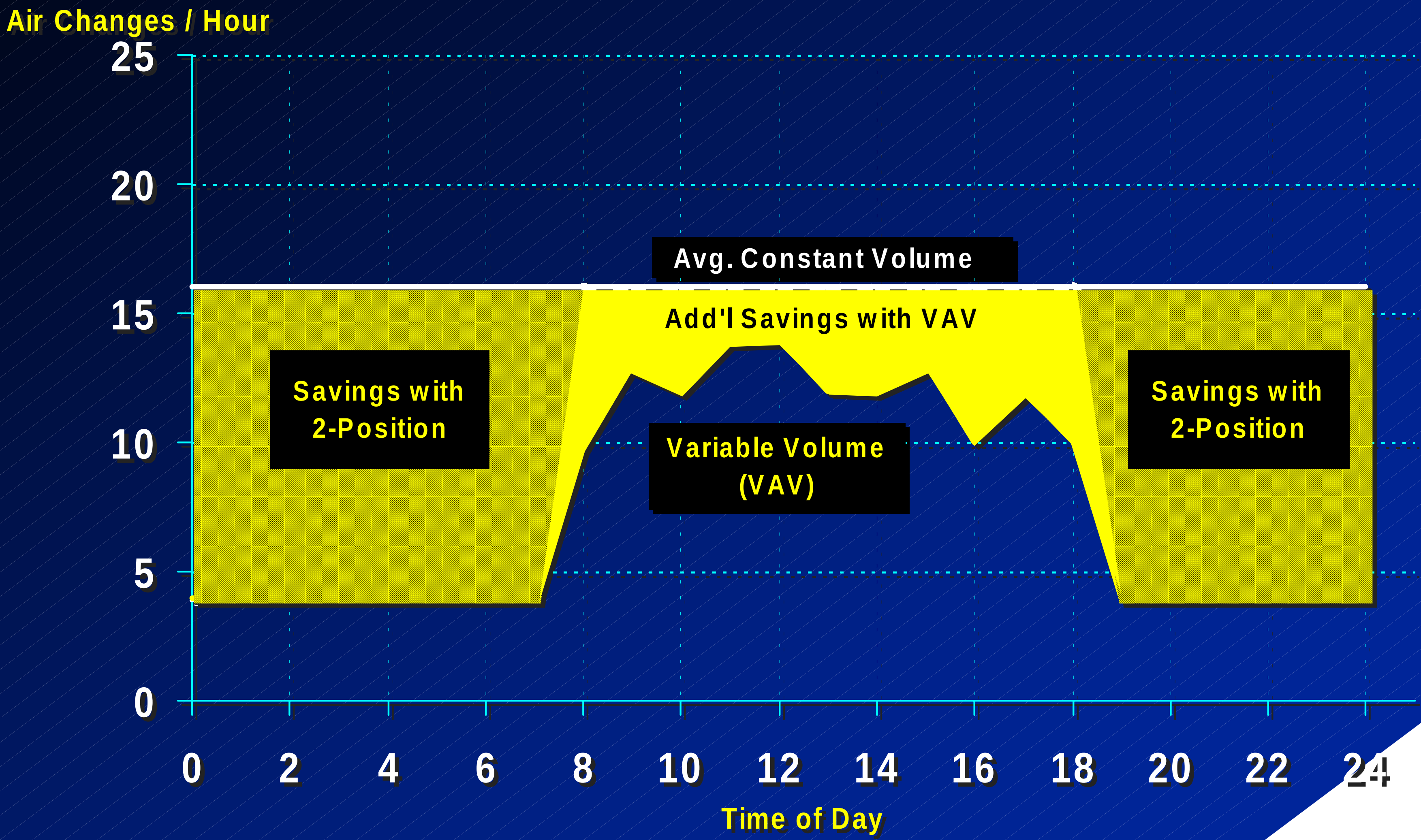

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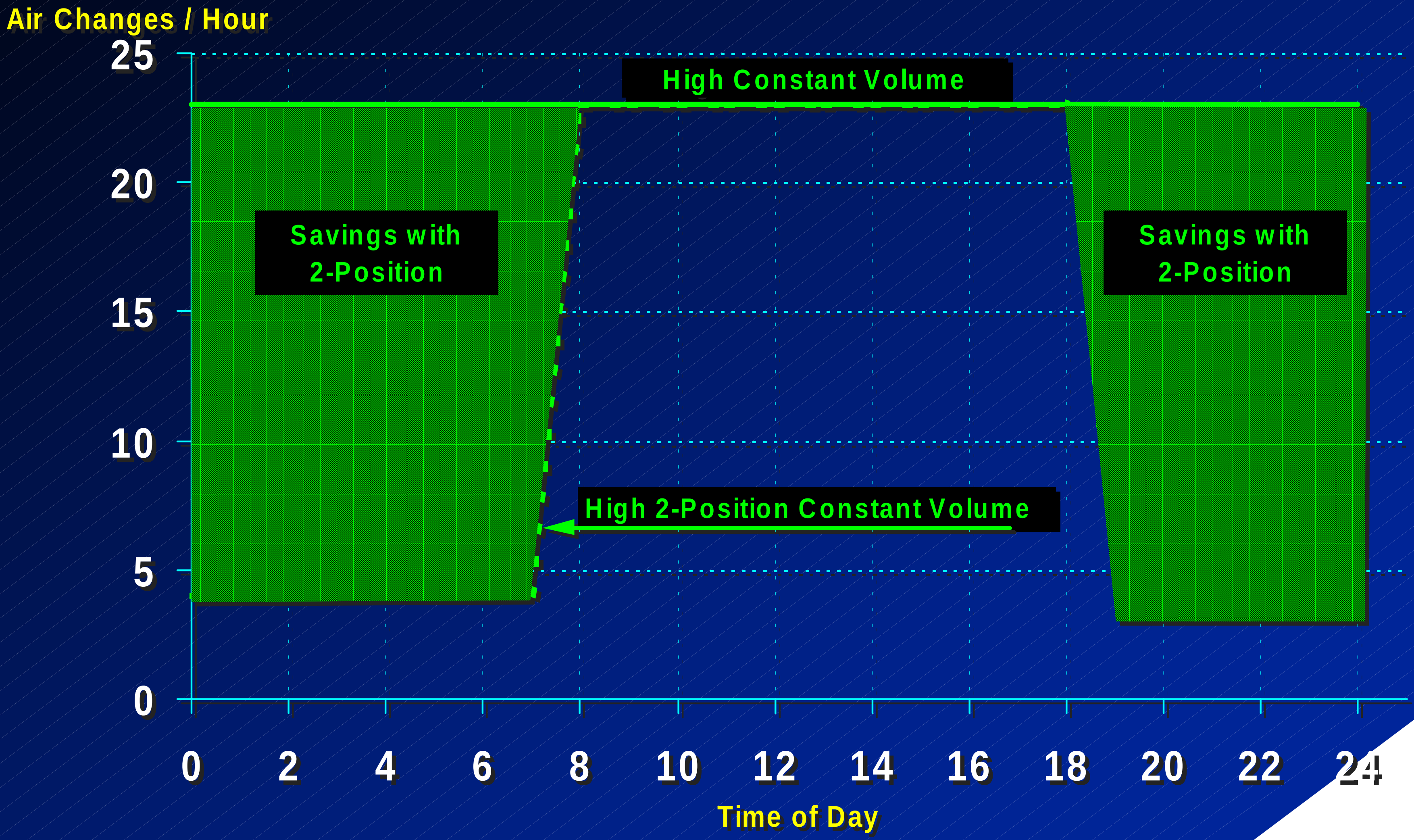

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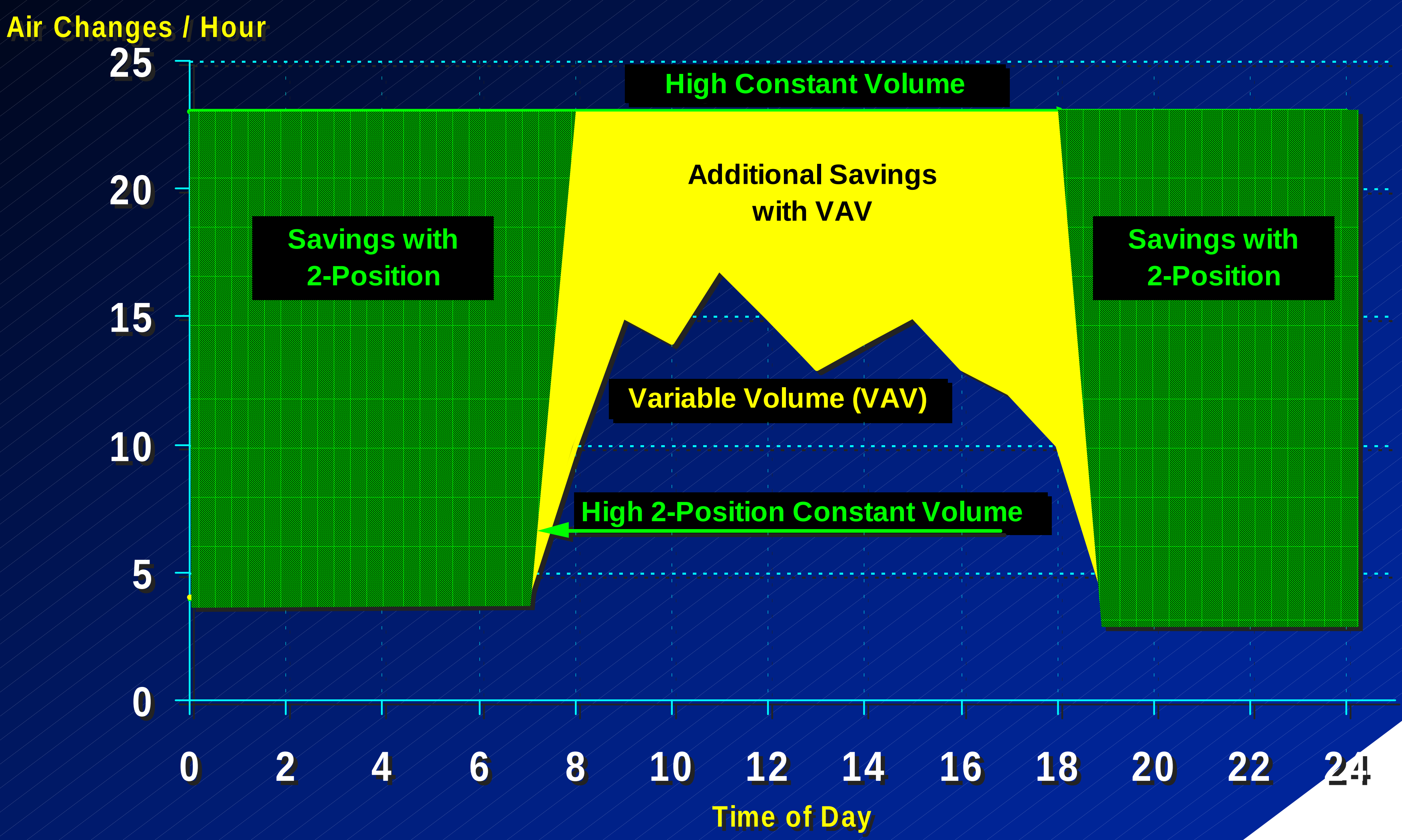

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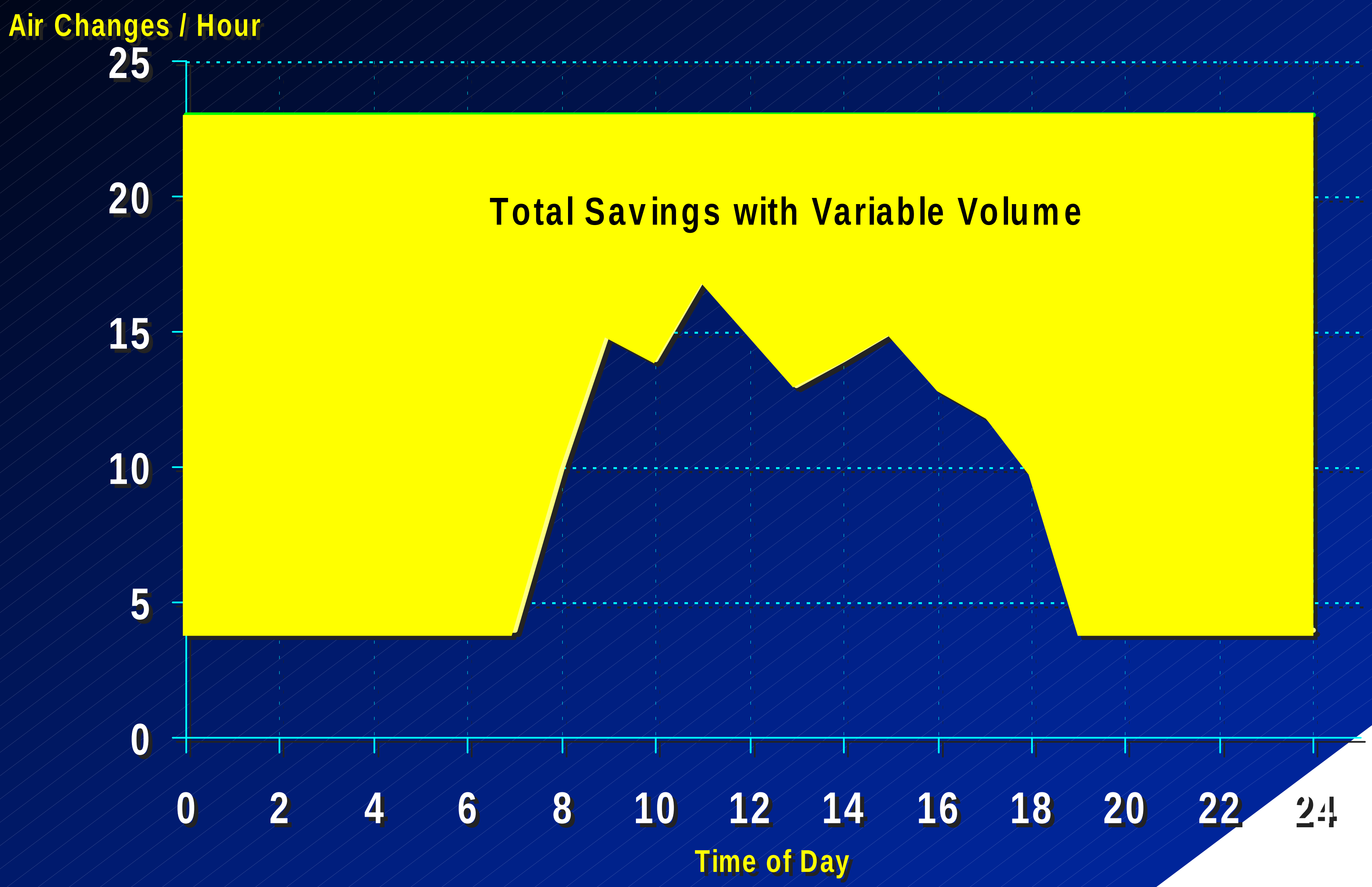

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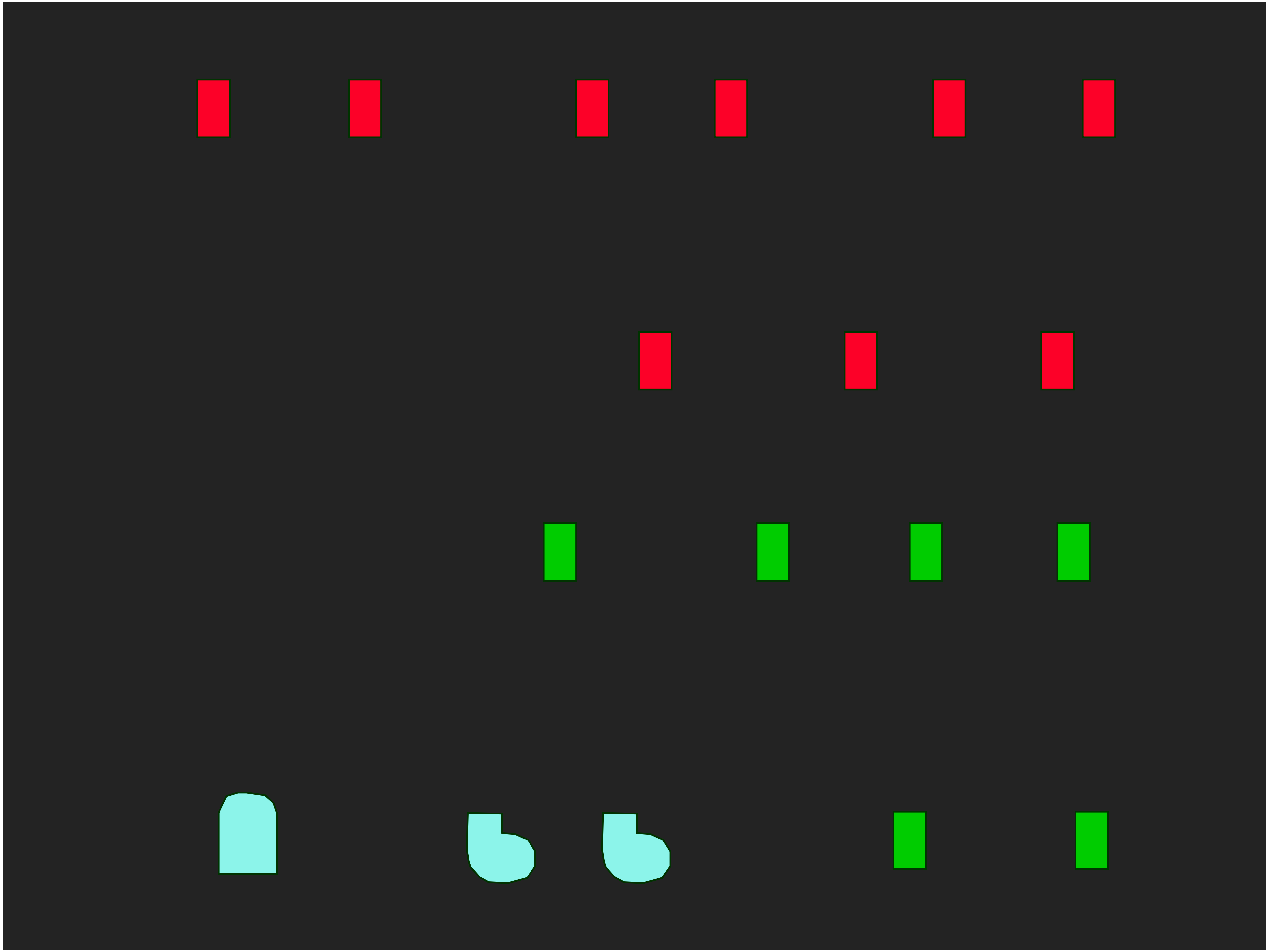
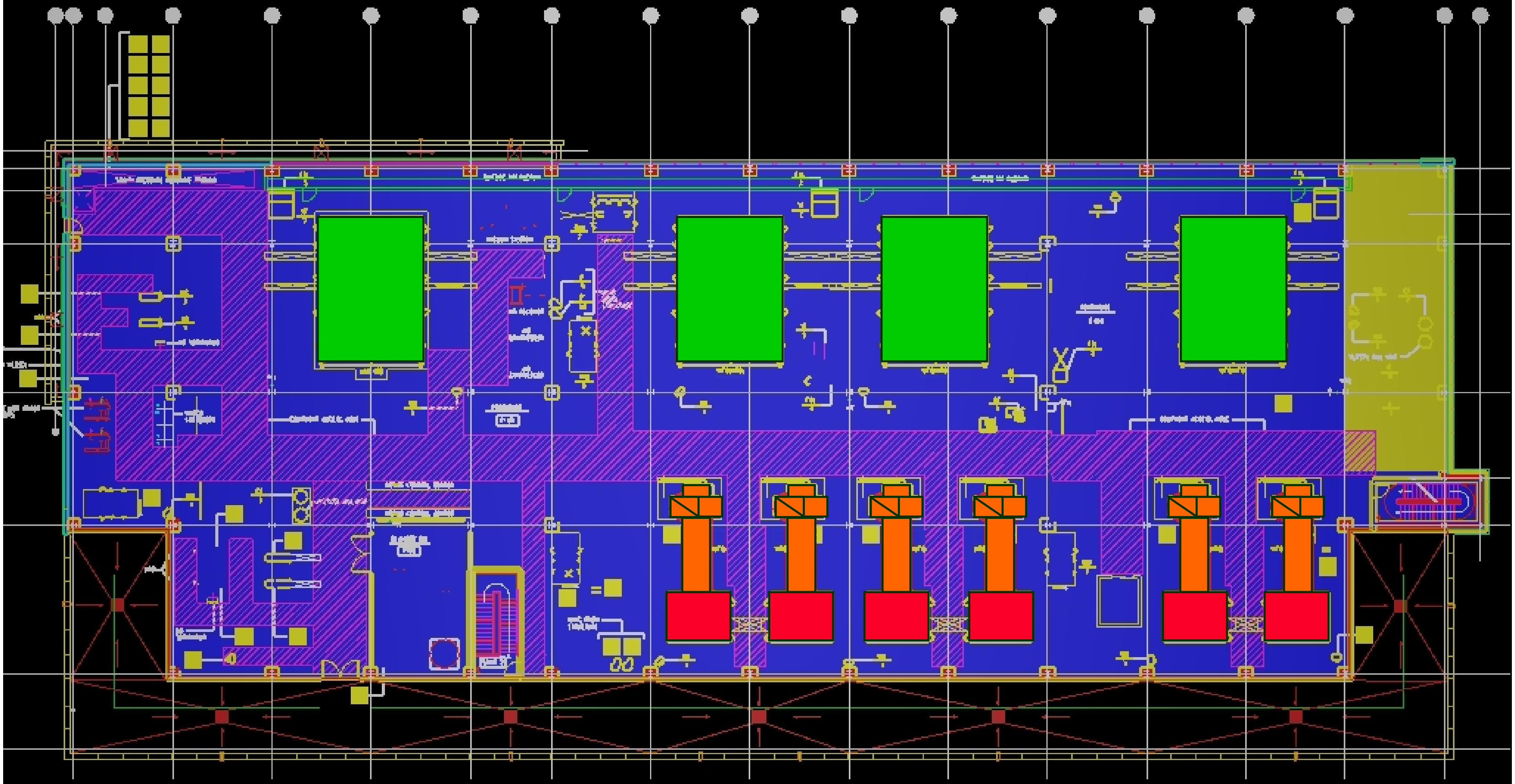
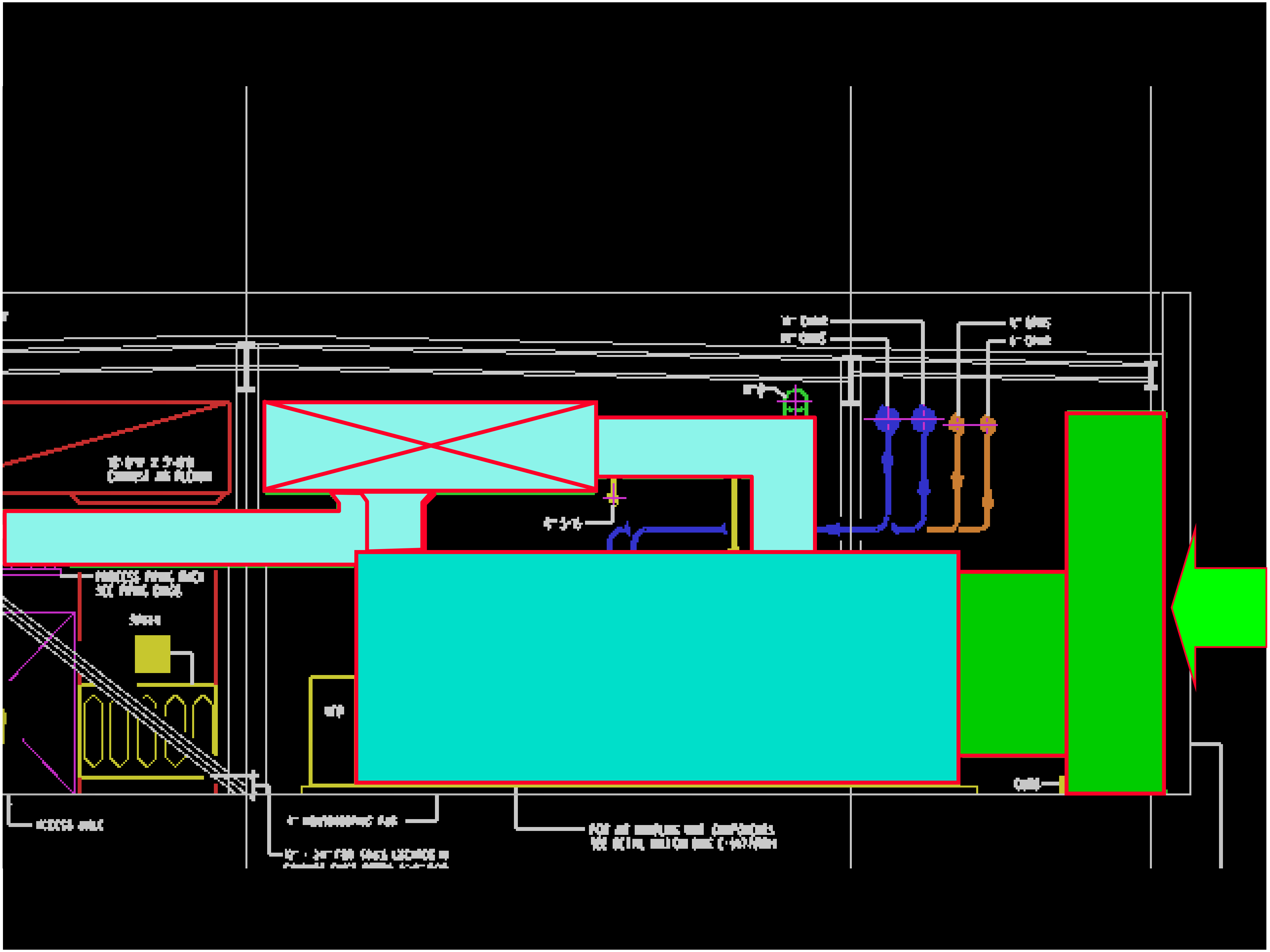
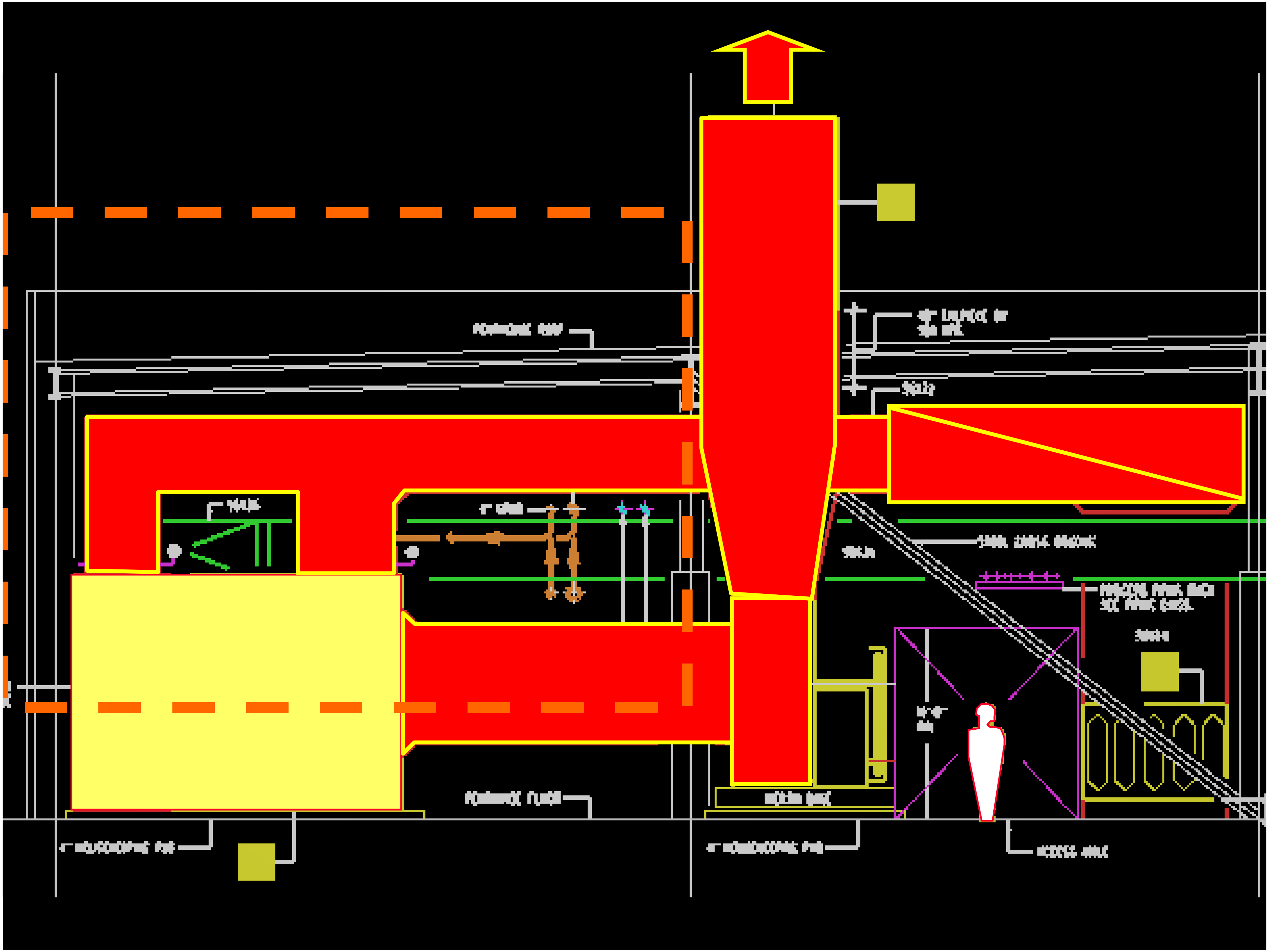
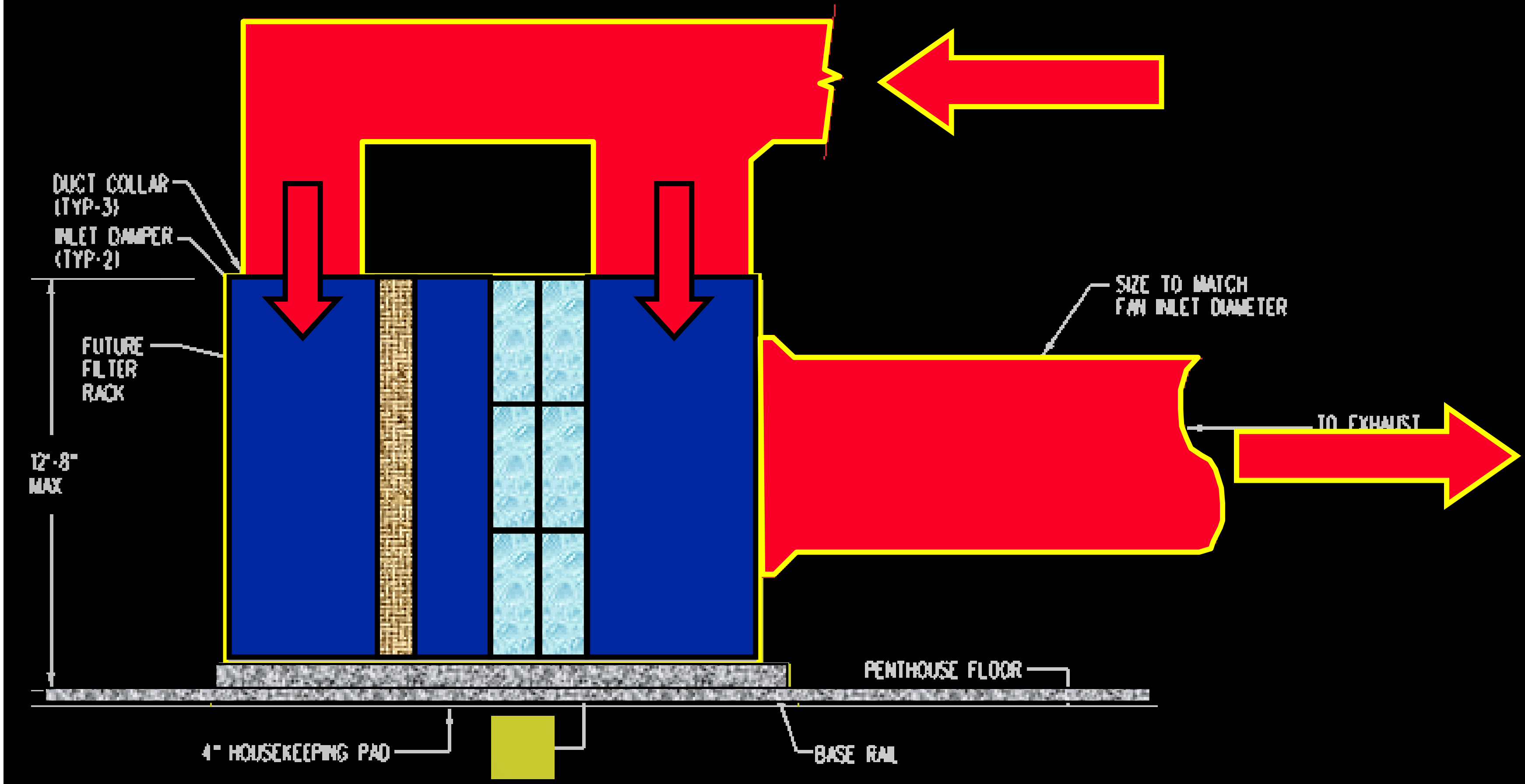
ASHRAE 1996 Systems Handbook	Fixed Plate	**Rotary Wheel**	Heat Pipe	**Run-Around Coil Loop**	Thermosiphon	Twin Towers
Airflow arrangements	Counterflow Crossflow Parallel flow	Counterflow Parallel flow	Counterflow Parallel flow	Counterflow Parallel flow	Counterflow Parallel flow	
Equipment size range, cfm	50 and up	50 to 70,000	100 and up	100 and up	100 and up	
Type of Heat Transfer (Typ.effectiveness	Sensible (50 to 80%)	Sensible (50 to 80%) Total (55 to 85%)	Sensible (45 to 65%)	Sensible (55 to 65%)	Sensible (40 to 60%)	Sensible (40 to 60%)
Face Velocity, fpm (typ. design vel.)	100 to 1000 (200 to 1000)	500 to 1000	400 to 800 (450 to 550)	300 to 600	400 to 800 (450 to 550)	300 to 450
Pressure drop, in. of water (typical pressure)	0.02 to 1.8 (0.1 to 1.5)	(0.4 to 0.7)	(0.4 to 2.0)	(0.4 to 2.0)	(0.4 to 2.0)	0.7 to 1.2
Temperature range	–70 to 1500°F	–70 to 1500°F	–40 to 95°F	–50 to 900°F	–40 to 104°F	–40 to 115°F
Typical mode of purchase	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case	Coil only Complete system	Exchanger only Exchanger in case	Complete system
Unique advantages	No moving parts Low pressure drop Easily cleaned	Latent transfer Compact large sizes Low pressure drop	No moving parts except tilt Fan location not critical Allowable pressure differential up to 60 in. of water	Exhaust airstream can be separated from supply air Fan location not critical	No moving parts Exhaust airstream can be separated from supply air Fan location not critical	Latent transfer from remote airstreams Multiple units in a single system Efficient microbiological cleaning of both supply and exhaust airstreams
Limitations	Latent available in hygroscopic units only	Cold climates may increase service Cross-air contamination possible	Effectiveness limited by pressure drop and cost Few suppliers	High effectiveness requires accurate simulation model	Effectiveness may be limited by pressure drop and cost Few suppliers	Few suppliers
Cross-leakage	0 to 5%	1 to 10%	0%	0%	0%	0.025%
Heat rate control (HRC) schemes	Bypass dampers and ducting	Wheel speed control over full range	Tilt angle down to 10% of maximum heat rate	Bypass valve or pump speed control over full range	Control valve over full range	Control valve or pump speed control over full range







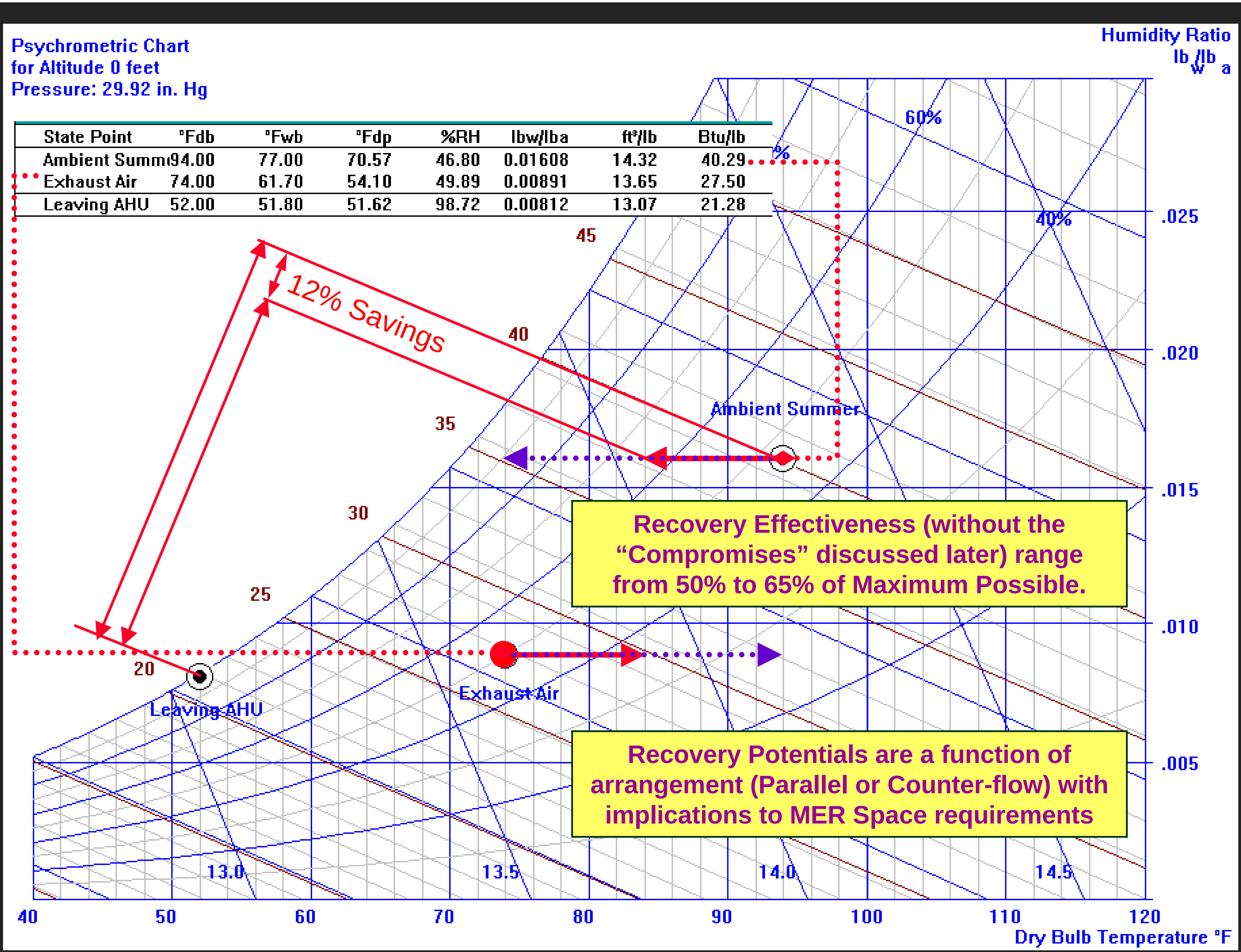




ELEVATION

HEAT RECOVERY UNIT DETAIL

(TYPICAL FOR HRU-1 THRU HRU-6)



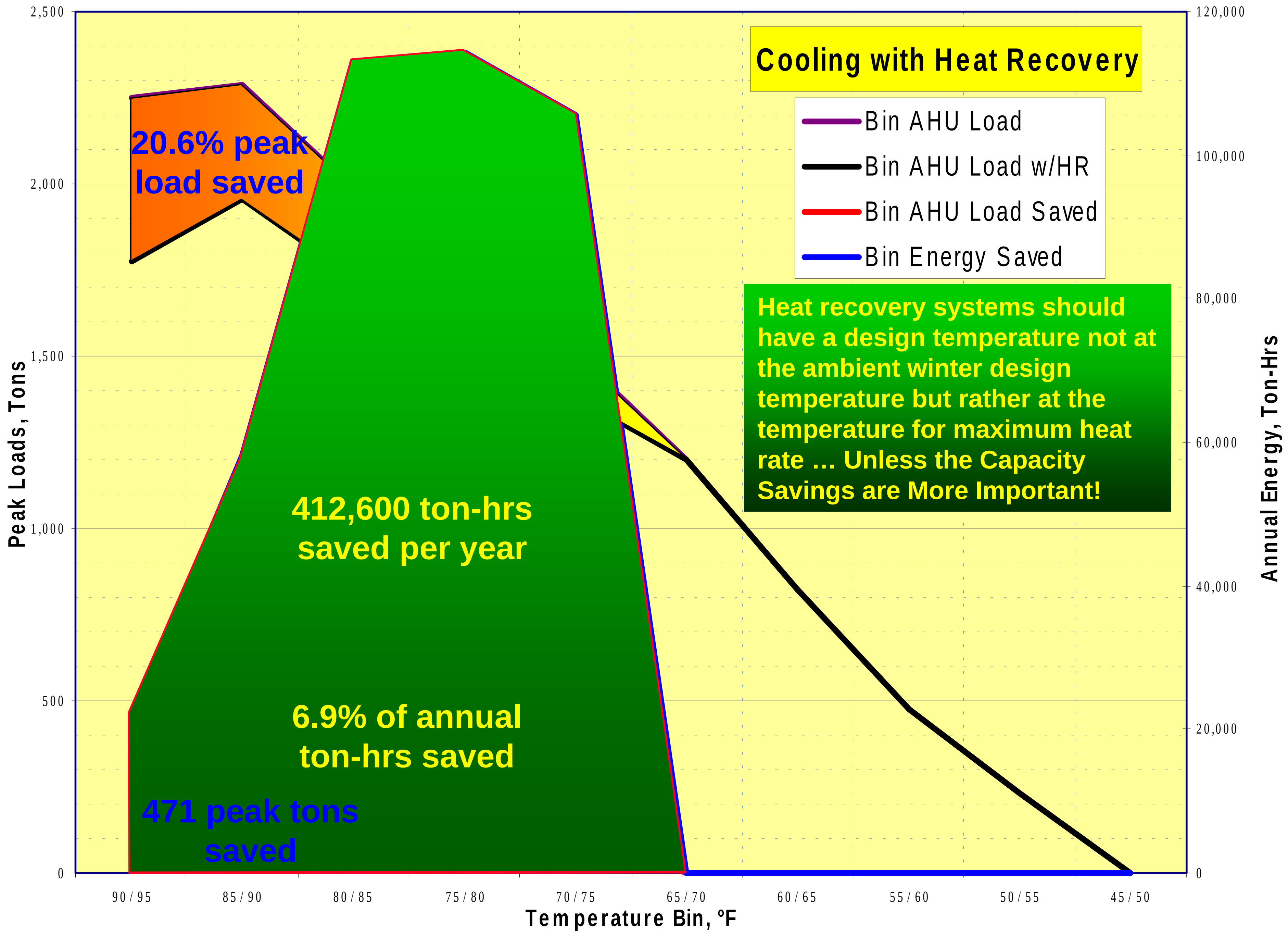
Psychrometric Chart
for Altitude 0 feet
Pressure: 29.92 in. Hg

State Point	°Fdb	°Fwb	°Fdp	%RH	lbw/lba	ft³/lb	Btu/lb
Ambient Summ	94.00	77.00	70.57	46.80	0.01608	14.32	40.29
Exhaust Air	74.00	61.70	54.10	49.89	0.00891	13.65	27.50
Leaving AHU	52.00	51.80	51.62	98.72	0.00812	13.07	21.28

Recovery Effectiveness (without the “Compromises” discussed later) range from 50% to 65% of Maximum Possible.

Recovery Potentials are a function of arrangement (Parallel or Counter-flow) with implications to MER Space requirements

Building XYZ Energy Savings		**System = 384,000 CFM**				
SYSTEM ANALYSIS		**Northern New Jersey**				
HEATING	**10°F DB Winter Ambient Design**					
Peak Heating Load without Heat Recovery:	42,825	mbh		Preheat is	40.4%	Total
Peak Steam Flow without Heat Recovery:	45,318	lbs/hr				
Peak Heating Load with Heat Recovery:					32,265	mbh
Peak Steam Flow with Heat Recovery:					34,143	lbs/hr



Cooling with Heat Recovery

20.6% peak load saved

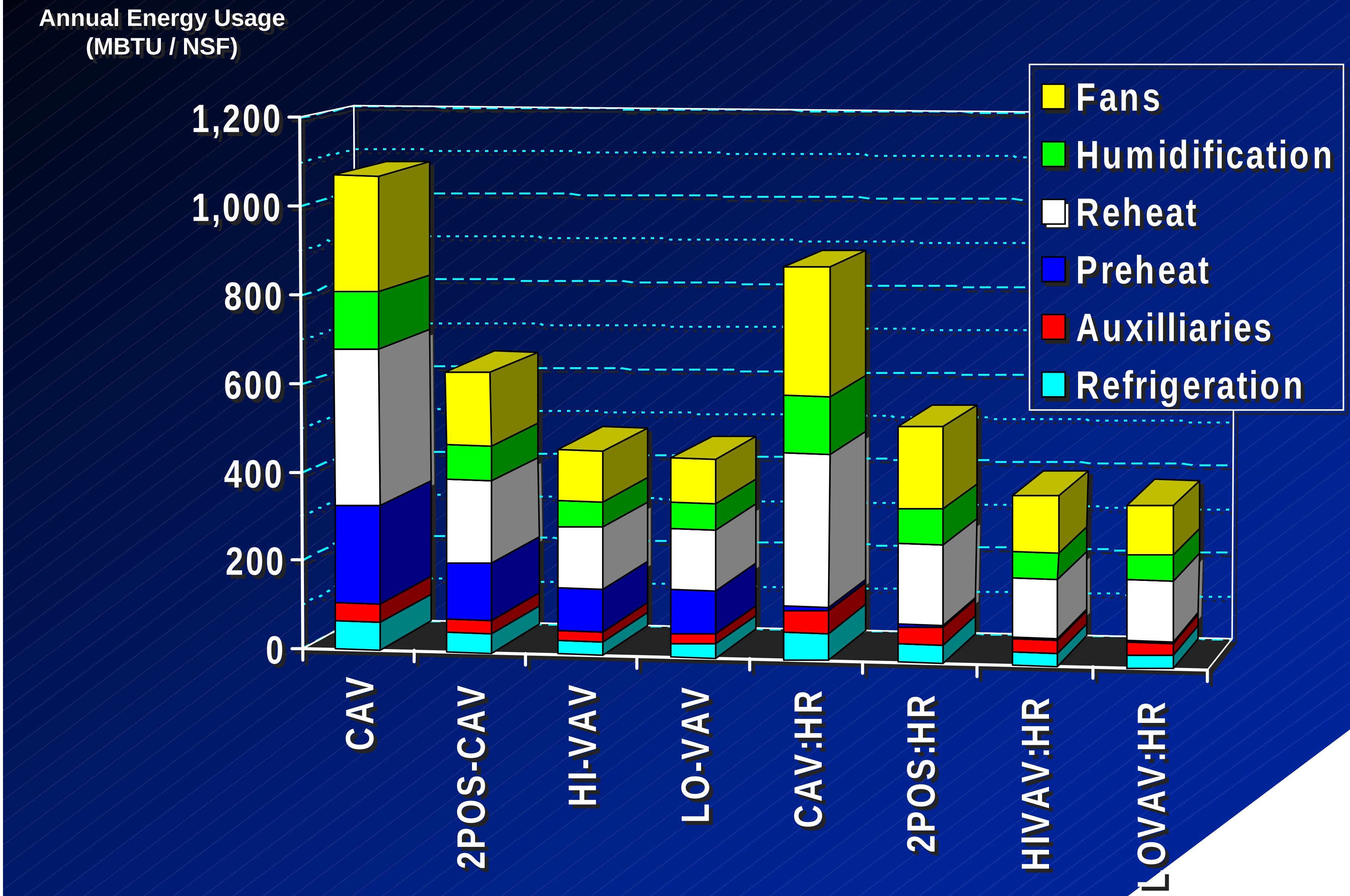
412,600 ton-hrs saved per year

6.9% of annual ton-hrs saved

471 peak tons saved

Heat recovery systems should have a design temperature not at the ambient winter design temperature but rather at the temperature for maximum heat rate … Unless the Capacity Savings are More Important!

ENERGY USAGE for LAB SYSTEMS by END USE



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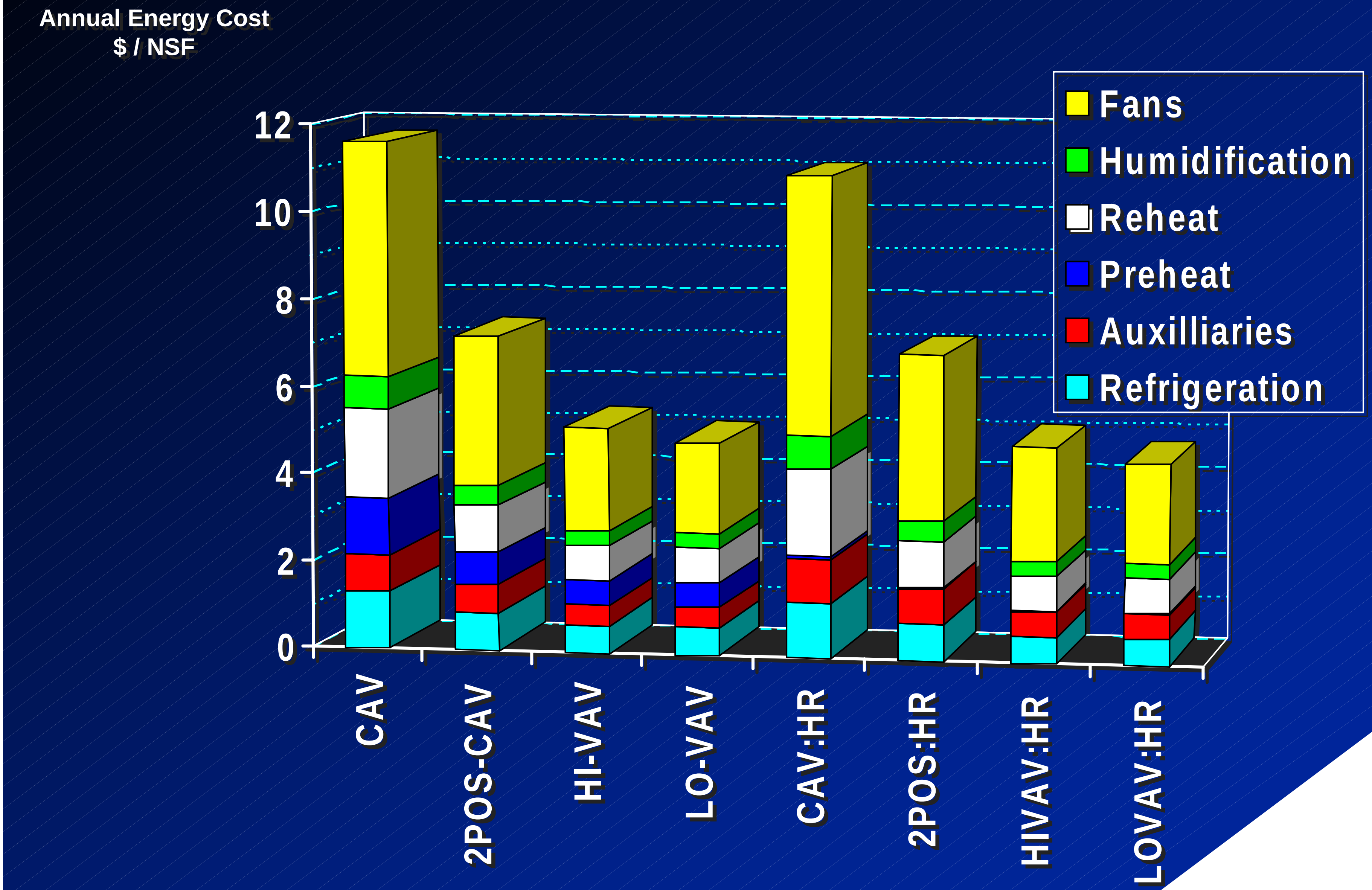
ENERGY COSTS for LAB SYSTEMS by END USE



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No Heat Recovery vs. Heat Recovery Operating Cost Comparison:

Item:	Without Heat Recovery Use		
	Unit Value		Operating Cost $US/yr
Chiller Energy	4,176,454	kwh/yr	$ 286,087
Chilled Water Pumping Energy	215	BHP	$ 96,188
Condenser Water Pumping Energy	313	BHP	$ 140,274
Cooling Tower Fan Energy	187	BHP	$ 83,900
Supply Fan Energy (All units)	564	BHP	$ 252,416
Exhaust Fan Energy (All Units)	483	BHP	$ 216,357
Heat Recovery Pump Energy (net add'l)	0	BHP	$ -
	2,402	BHP	
	1,792	KW	
Plant Steam Energy	89,822,453	lbs/hr/yr	$ 947,627
TOTALS			$2,022,850

Estimated Cost of Initial Investment: (Add'l Capital Req'd for Heat Recovery Equip. & Utilities)

						Cost
Heat Recovery Coil First Cost:		45,000	$US/coil	6	# of coil	$ 270,000
Additional Exh. Ductwork First Cost:		7	$US/lb	8,906	lbs of sheet metal	$ 62,339
Pumping System First Cost		30,000	US dollars	1	# of systems	$ 30,000
Additional Piping Cost		55	$/ft	720	ft. of piping	$ 39,600
HR Start-up Cost:		2,000	$US/coil	6	# of coils	$ 12,000
HR Coil Control Installation Cost:		6,000	$US/coil	6	# of coils	$ 36,000
Building Floor Area Cost:	note 1	0	$US/sq.ft.	3,500	# of sq.ft. req'd (additional)	$ -
Building Wall Area Cost:	note 1	0	$US/ln.ft.	5	# of ft. req'd (additional)	$ -
(Increased Roof Height to fit equipment)						
					Total:	**$ 449,939**
Additional Chiller Avoidance Savings:		2,538	$/ton	323	# of tons saved (peak)	$ 819,944
Additional Boiler Avoidance Savings:		80,000	$/kpph	11	# kpph steam saved (peak)	$ 893,968
Estimated First Cost Investment of HR Equipment:						$ 449,939
						$ 1,263,973
Project Capital Cost Savings:						**$ 1,263,973**
Energy Savings per year including the first year:						**$ 139,300**

Basic Question 3 – Given the Number of Variables, Is Optimization of Heat Recovery Feasible? … based on What Goals or Priorities?

- Operating Costs? … Based on
  - Marginal Fuel / Energy Costs?
  - Extended Costs including Maintenance and Equipment?
- First Costs?
  - Actual Installation?
  - Avoided Costs (including Tax and other Financial impacts)
- Life Cycle Costs?
  - Energy Costs?
  - Maintenance Costs?
  - First Costs?
  - Replacement Costs
  - Based on what Time-Frame and What Financial Factors?
- Benchmark Thresholds?
  - Simple Payback?
  - Internal Rate of Return?
  - Return on Investment?
- Are Investments in the Future Realistic Given Typically Tight Project Budgets and Cost Constraints?

Basic Question 4 – What Situations or Realities of Projects and Budgets Typically Compromise the Optimal Solutions?

- Use of **Return Air**, which is much more energy efficient, will likely cut into the Overall Heat Recovery “Opportunity” by
  - Complicating the Location / Arrangement of the Outside Air “Preheat” Recovery Coil (space, controls and SP implications) or
  - Reduce the Maximum Potential Recovery Effectiveness by reducing the Maximum Available Recovery Temperature Differential … could reduce effectiveness from 50-60% to as low as 40-50%!
- Use of the **Same Heating Coil for Recovery and for Supplemental Preheat** will minimize some of the Air Pressure Drops on the Supply Air Handling Units (AHUS), but using another heat exchanger in series with the Heat recovery Coil Loop will likely cut into the Overall Heat Exchange Effectiveness because of inability to Optimally Control a Coil/Valve to Prevent “overheating” being sent to the Exhaust Air Coil
- Needs to **Maintain Exhaust Stack Velocity** on Systems that Turn-Down with VAV necessitate either Bypass Arrangements around the Exhaust Coil or Exhaust Inlet Make-up that cuts into recovery.

Summary of "Basics" for Heat Recovery Systems

- Contamination (Chemical, Odor, etc.) and Corrosion Issues Strongly Suggest More Emphasis on Sensible Only Recovery and Less on Latent!
- Larger "devices" = Lower Velocities = Lower S.P Drops = Less Fan Energy and Improved Heat Exchange Effectiveness, but Physical Implications have Associated Costs!
- The Economies of Scale Favor Larger Installations … But again the Physical Implications Increase Accordingly!
- The Needs to Improve the Separation of Supply Intakes and Exhaust Discharges Make Direct Heat Exchanger Systems (Flat Plate, Heat Pipe, Rotary Wheel, etc.) More Problematic because of Physical Implications of Large Ductwork in Combined MERs.
- Relative Scale of Mass (Not Volume) Flows will impact overall Effectiveness … but the "Advantage" from more Exhaust vis-à-vis Supply/Outside Air is Rarely Possible!
- Typical Installed Cost/CFM: $2.00 to $5.00 (excl. "space issues")
- Typical Annual Operating Cost Savings per CFM: $0.25 to $1.00

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