NORTHEAST USA | INTEGRATED SCIENCES BUILDING

Christopher S. Putman | Mechanical Option
Faculty Advisor | Dr. William Bahnfleth

Presentation Outline

- Building Information
- Existing Mechanical Systems
- Building Energy Consumption
- Re-Design Goals
- Mechanical Upgrades
  - Variable Primary Flow (MAE)
  - Latent Thermal Storage (MAE)
- Construction Breadth – Thermal Storage Changes
- Electrical Breadth – Solar Photovoltaic System
- Conclusion & Summary
- Acknowledgements

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Building Information

Project Information

Size| 133,847 Square Feet

5 Stories Above Grade
6th-Level Mechanical Penthouse
Partial Basement

Occupancy | Educational & Research Laboratory
Construction Cost | $52.1 million
Construction Schedule | October 2009-July 2011
Delivery Method| Design-Bid-Build

Architecture

- LEED Gold Certification
- 5-Story Bio Wall
- 240-Seat Auditorium
- Laboratories & Science Classrooms
- Ground Floor Café
- Recycled Stone Exterior Cladding

Project Team

Owner | Information not for Publication
Architect | Diamond + Schmitt Architects, Inc.
Associate Architect | H2L2 Architects & Planners, LLC
General Contractor | Turner Construction Company
MEP Engineer | Crossey Engineering, Ltd.
MEP Engineer | Spotts, Stevens, & McCoy, Inc.
Structural Engineer | Halcrow Yolles Ltd.
Associate Structural Engineer | Keast & Hood Co.
Civil/Landscape | Stantec Consulting Services, Inc.

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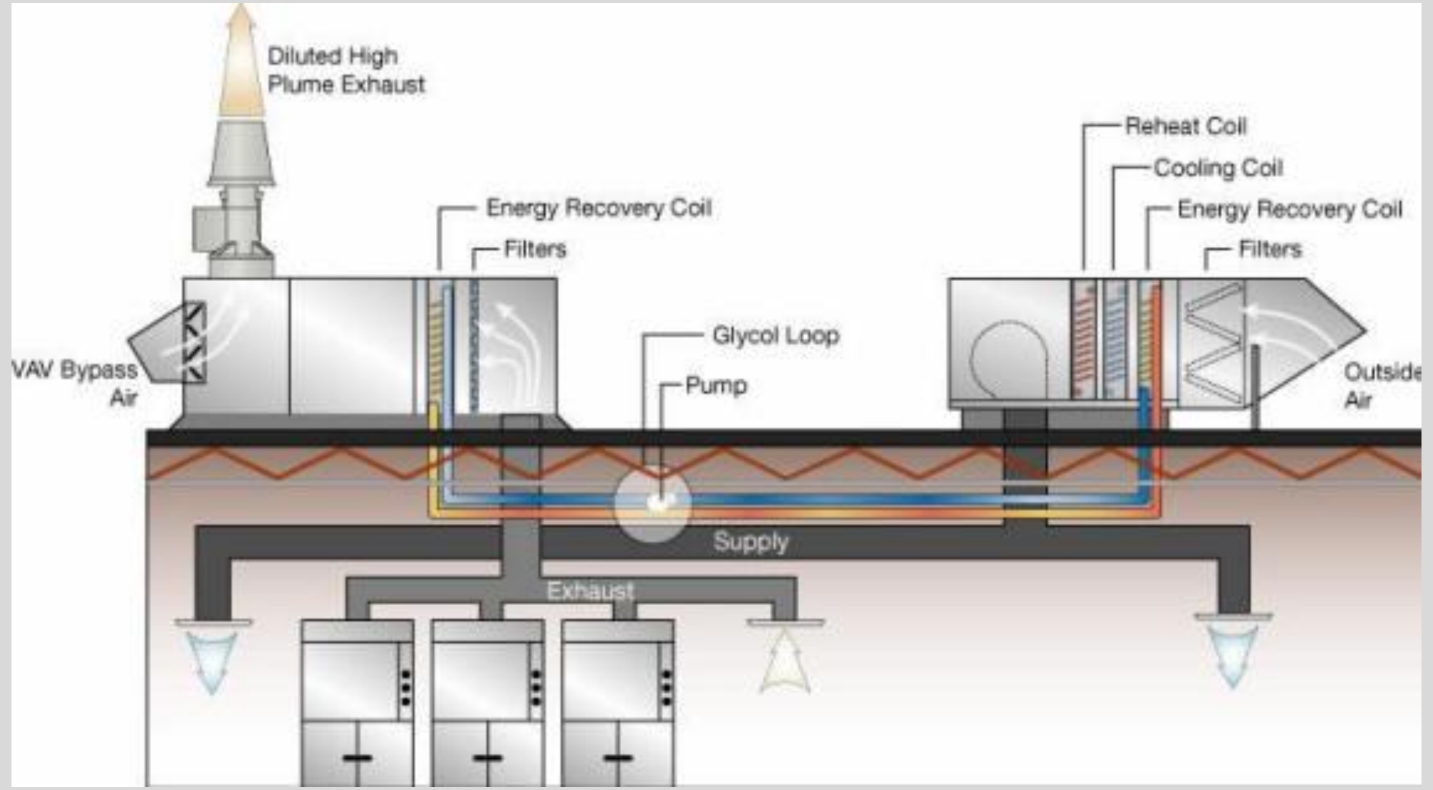
Existing Mechanical Systems

- **9 Air Systems**
  - VAV Systems w/ Hydronic Reheat
    - (4) Laboratory – 100% OA w/ Runaround Heat Recovery
    - (4) Offices/Classrooms/Atrium
  - CAV System
    - (1) Electrical & Data Closets



Run-Around Heat Recovery Coil Schematic

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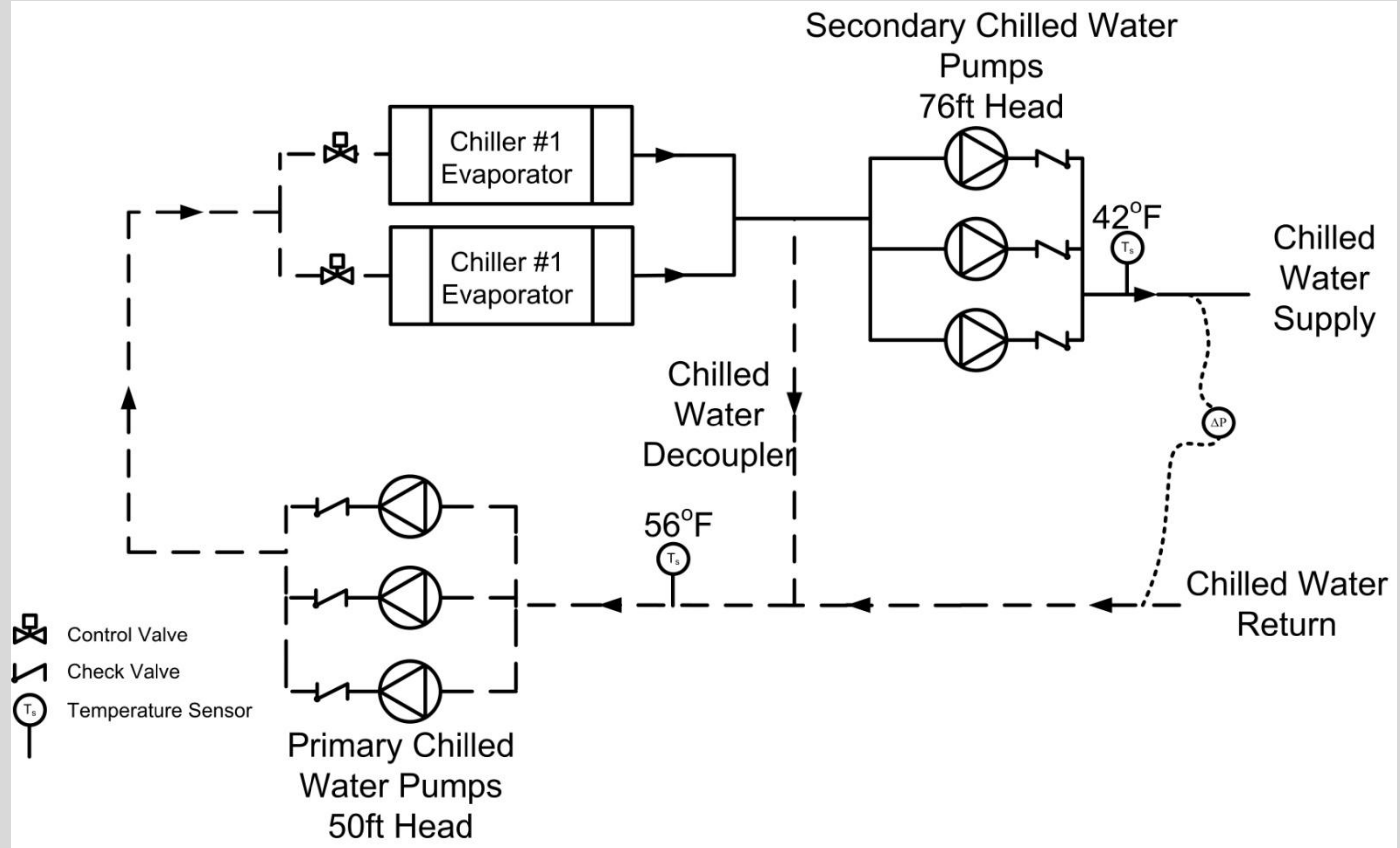
    - (4) Laboratory – 100% OA w/ Runaround Heat Recovery
    - (4) Offices/Classrooms/Atrium
  - CAV System w/ Hydronic Reheat
    - (1) Electrical & Data Closets
- **Chilled Water System**
  - (2) 620-ton Centrifugal Water-Cooled Chillers
  - (2) 620-ton Direct, Induced Draft Cooling Towers
  - Primary/Secondary Pumping System



Primary/Secondary Chilled Water System

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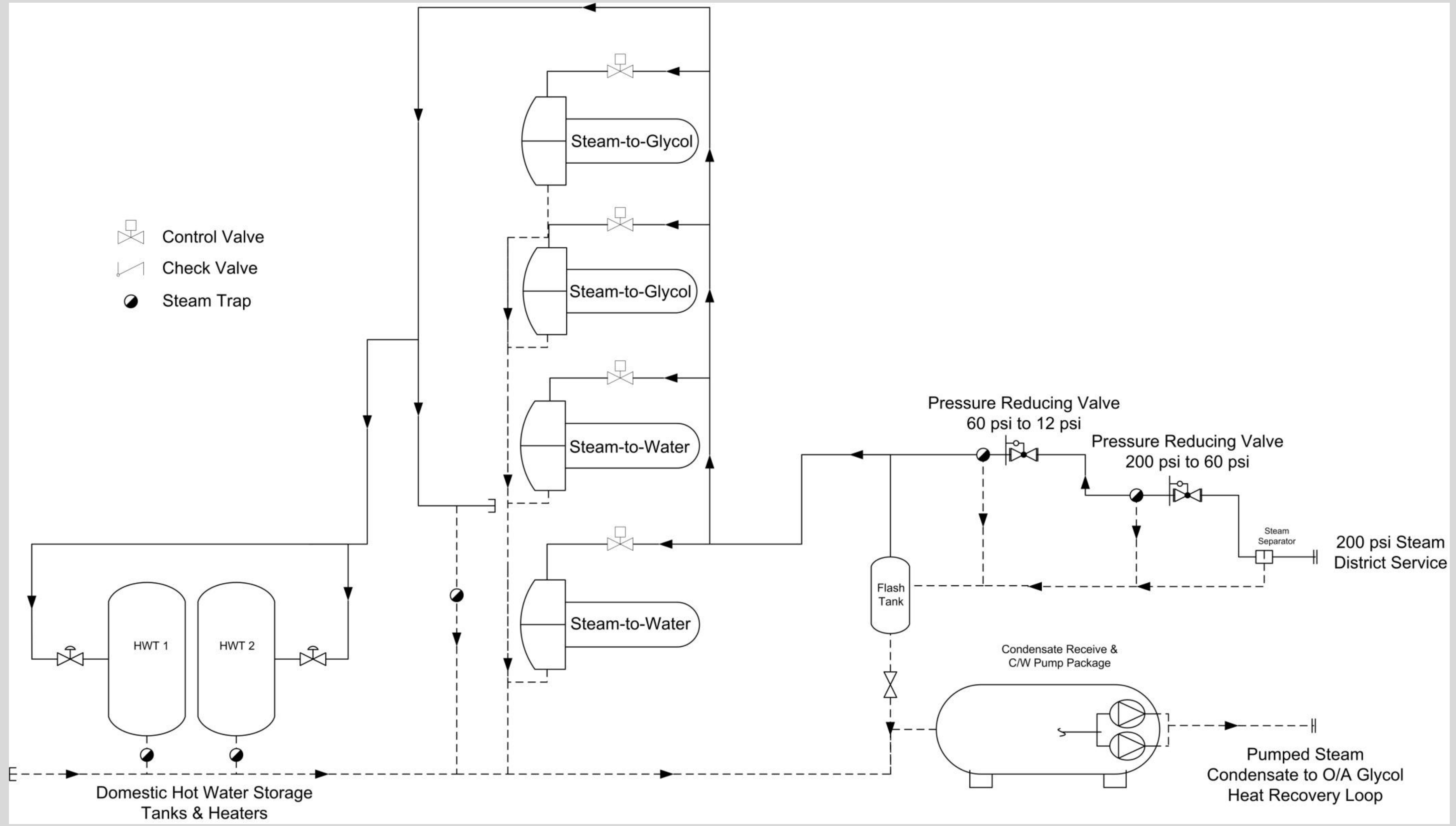
    - (4) Offices/Classrooms/Atrium
  - CAV System w/ Hydronic Reheat
    - (1) Electrical & Data Closets
- **Chilled Water System**
  - (2) 620-ton Centrifugal Water-Cooled Chillers
  - (2) 620-ton Direct, Induced Draft Cooling Towers
  - Primary/Secondary Pumping System
- **Hot Water System**
  - 200 psig District Steam Supply
  - Two Pressure Reducing Stations to 12psig
  - (2) 5105 lb/hr HXs – 30% Glycol 180°F
  - (2) 4500 lb/hr HXs – Water at 180°F



Steam Distribution System

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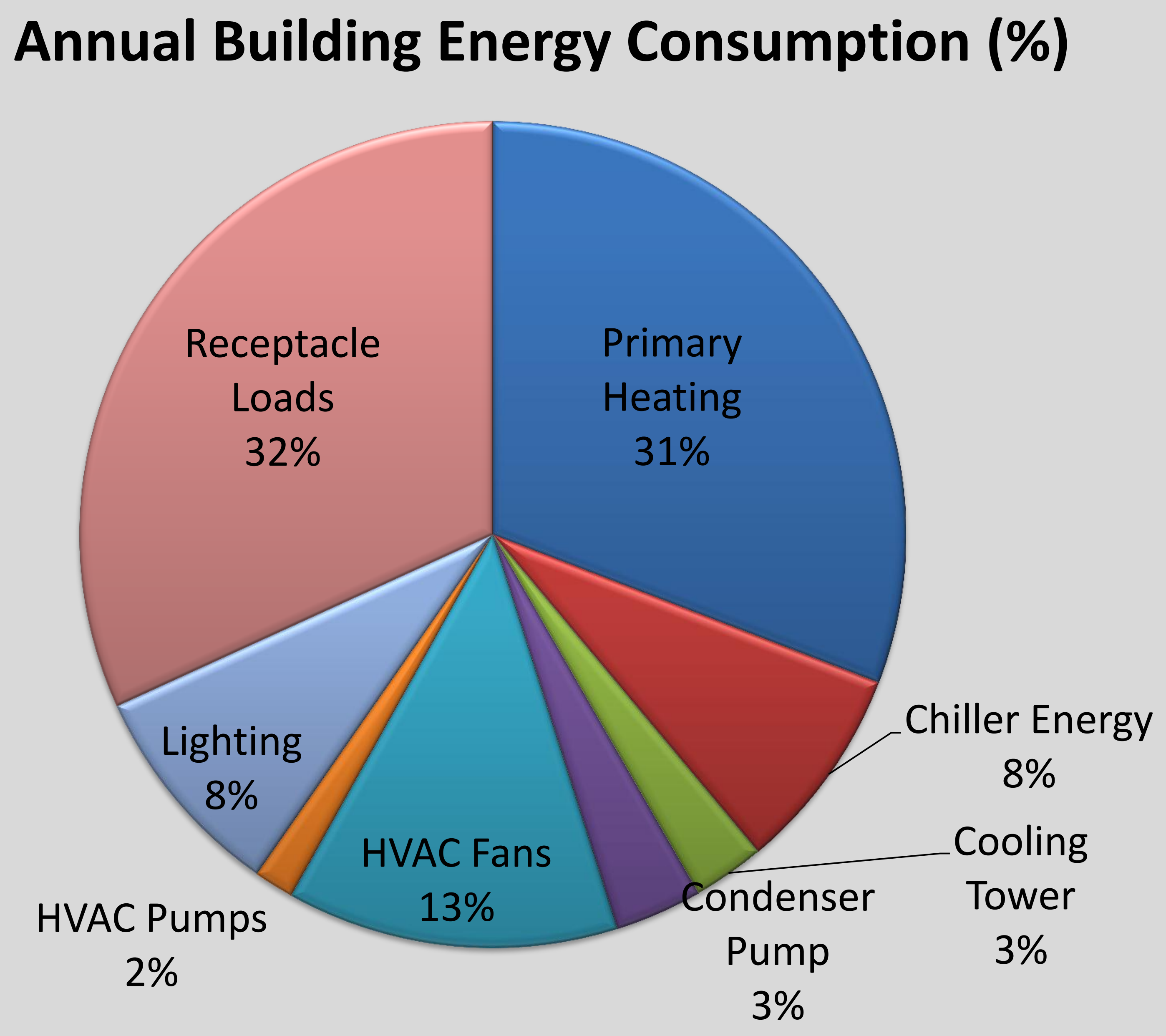
Building Energy Consumption

Annual Building Energy Consumption			
Function	Electricity (kWh)	Steam (kBtu)	kBtu/year
Primary Heating	-	4,537,606	4548646
Chiller Energy	349,031	-	1191243
Cooling Tower	121,524	-	414761
Condenser Pump	147,250	-	502564
HVAC Fans	561366	-	1915942
HVAC Pumps	67,930	-	231845
Lighting	368,045	-	1256137
Receptacle Loads	1,375,321	-	4693970
Total Consumption	2,993,701	4,537,606	14755108



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Mechanical Re-Design Goals

- **Overall Goals**
  - Minimize Maintenance
  - Reduce Emissions
  - Reduce Costs – Capital & Operating
- **Evaluation**
  - Electrical Bills
  - Life Cycle Cost
  - Emissions Impact

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Variable Primary Flow System (MAE)

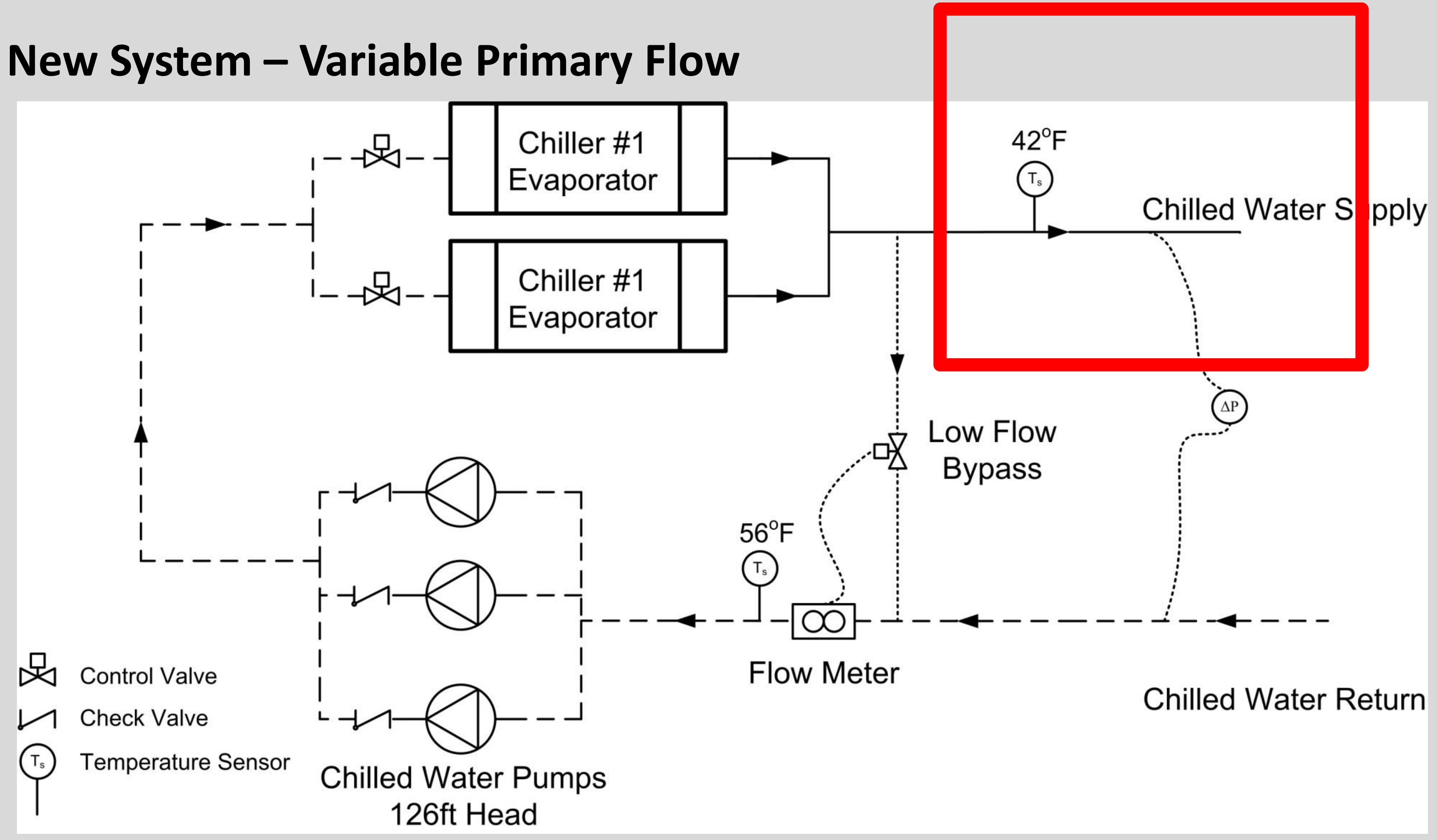
Immediate Benefits

- Fewer Pumps
- Less Pumping Energy
- Reduced Annual Electrical Consumption
- Low ΔT Tolerance

Drawbacks

- Control Stability & Reliability
  - Open Loop Control Based on Inlet temperature
- Variable Flow Chiller Capability
  - New Chillers can Handle ΔV
- Typically Overhyped
  - Proven with Parametric Study

New System – Variable Primary Flow



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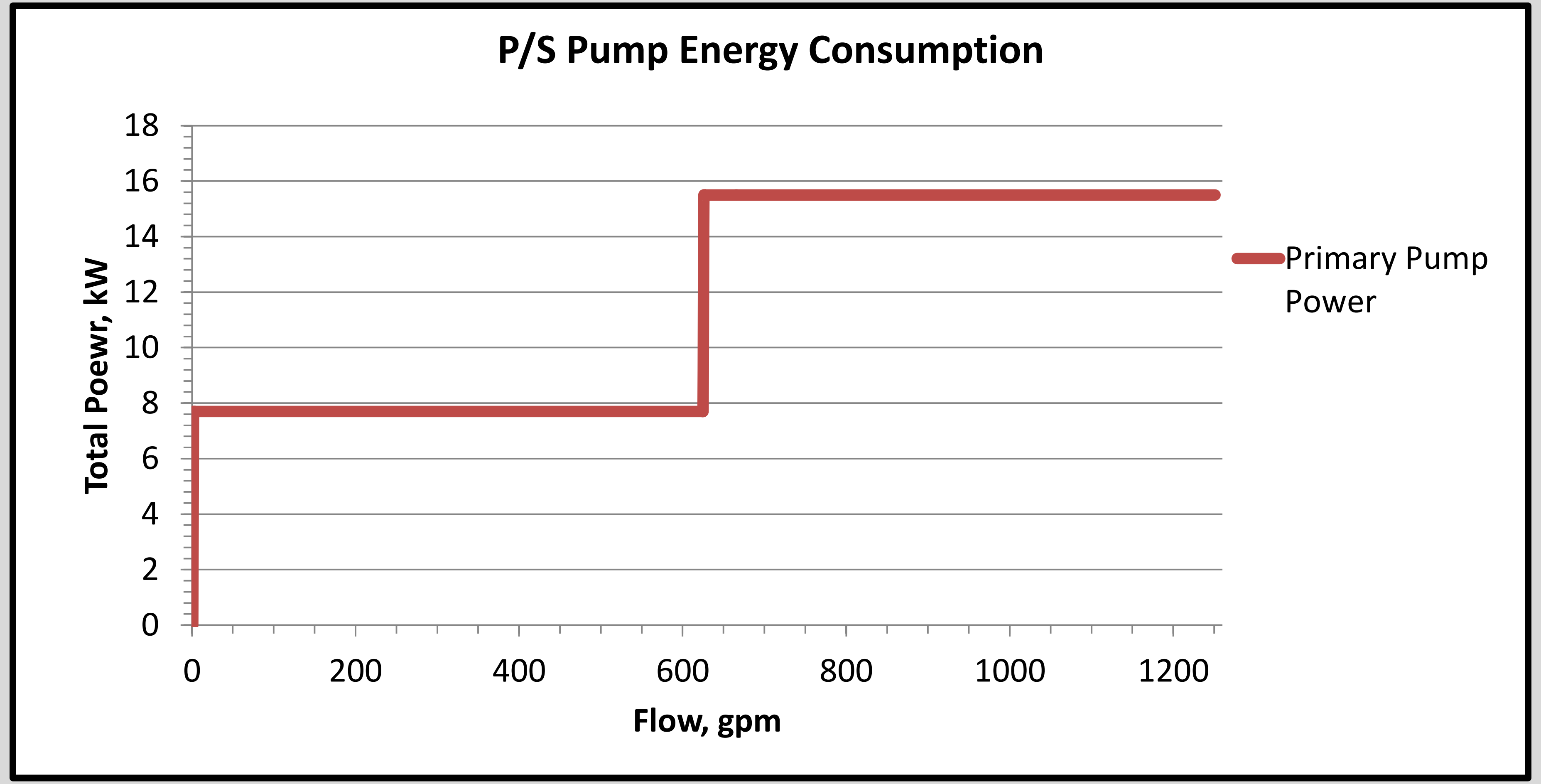
VARIABLE PRIMARY FLOW SYSTEM (MAE)

Original Primary/Secondary System

- **Primary Pumps – Bell & Gossett 1510-3BC**
  - (2) Duty Pumps + (1) Standby Pump
    - 50 ft Head
    - 15 HP
    - 625 GPM
    - $\eta_{Primary\ Pump} = 73\%$
    - $\eta_{Motor} = 95\%$
    - WHP= $(Q \times H)/(3960 \times \eta_{Primary})$
    - kW = $0.746 \times WHP/(\eta_{Motor}) = 8.5$kW



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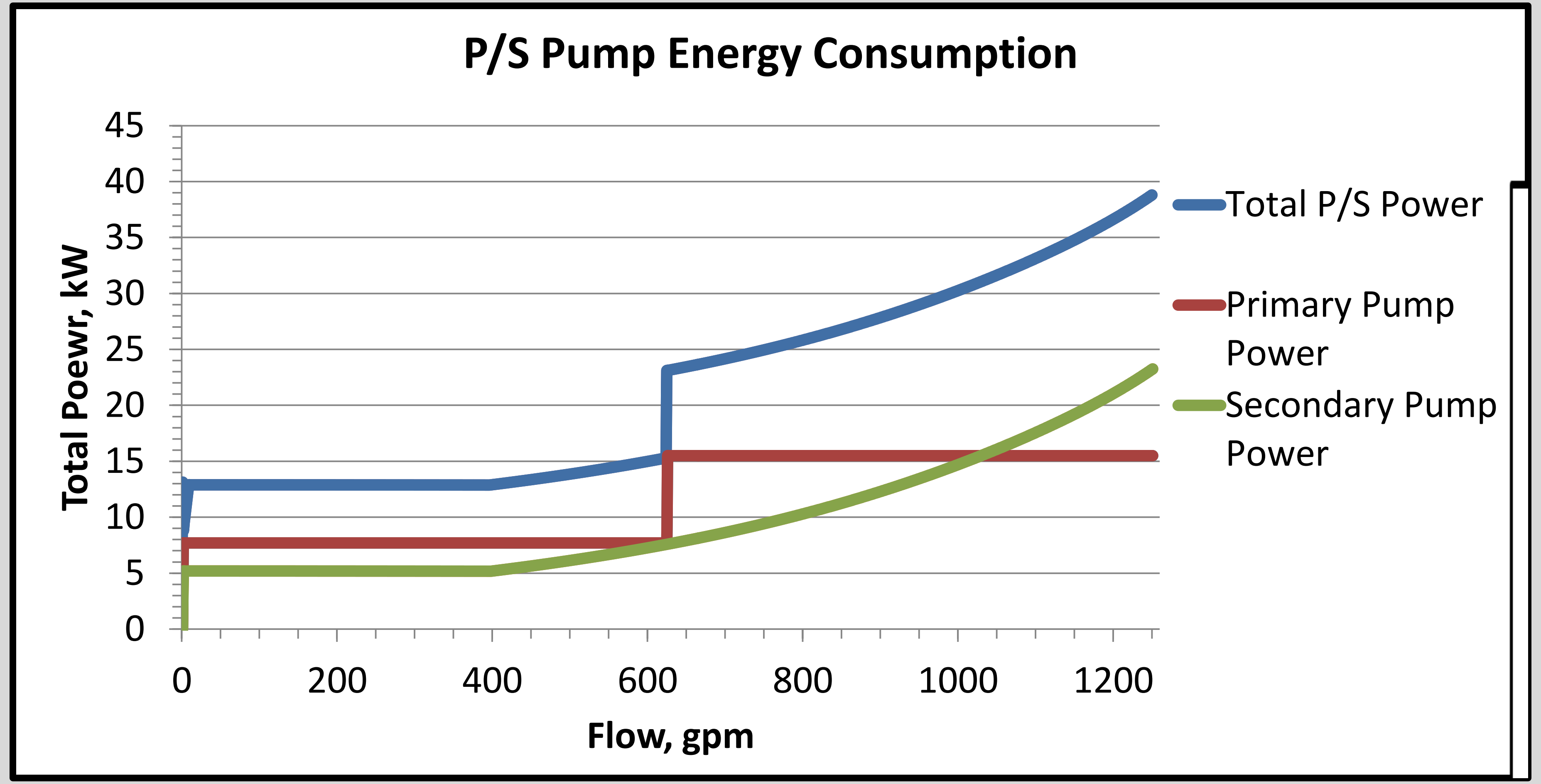
Variable Primary Flow System (MAE)

Original Primary/Secondary System

- **Secondary Pumps – Bell & Gossett 1510-4BC**
  - (2) Duty Pumps + (1) Standby Pump
    - $H_{secondary} = f(Q_{Actual}, N_{Actual})$
    - $P_{Nameplate} = 15$ HP
    - $Q_{Design} = 625$ GPM
    - $\eta_{Secondary\ Pump} = f(Q_{Actual}, N_{Actual})$
    - $\eta_{Motor} = f(P_{Shaft}, P_{Nameplate})$
    - $\eta_{VFD} = f(N_{Actual}, N_{Secondary})$
    - $H_{system} = H_{fixed} + [H_{Design} + H_{fixed}][Q_{Actual}/Q_{Design}]$
    - $WHP = (Q_{Actual} \times H_{System})/(3960 \times \eta_{Secondary})$
    - $kW = 0.746 \times WHP/ (\eta_{Motor} , \eta_{VFD})$



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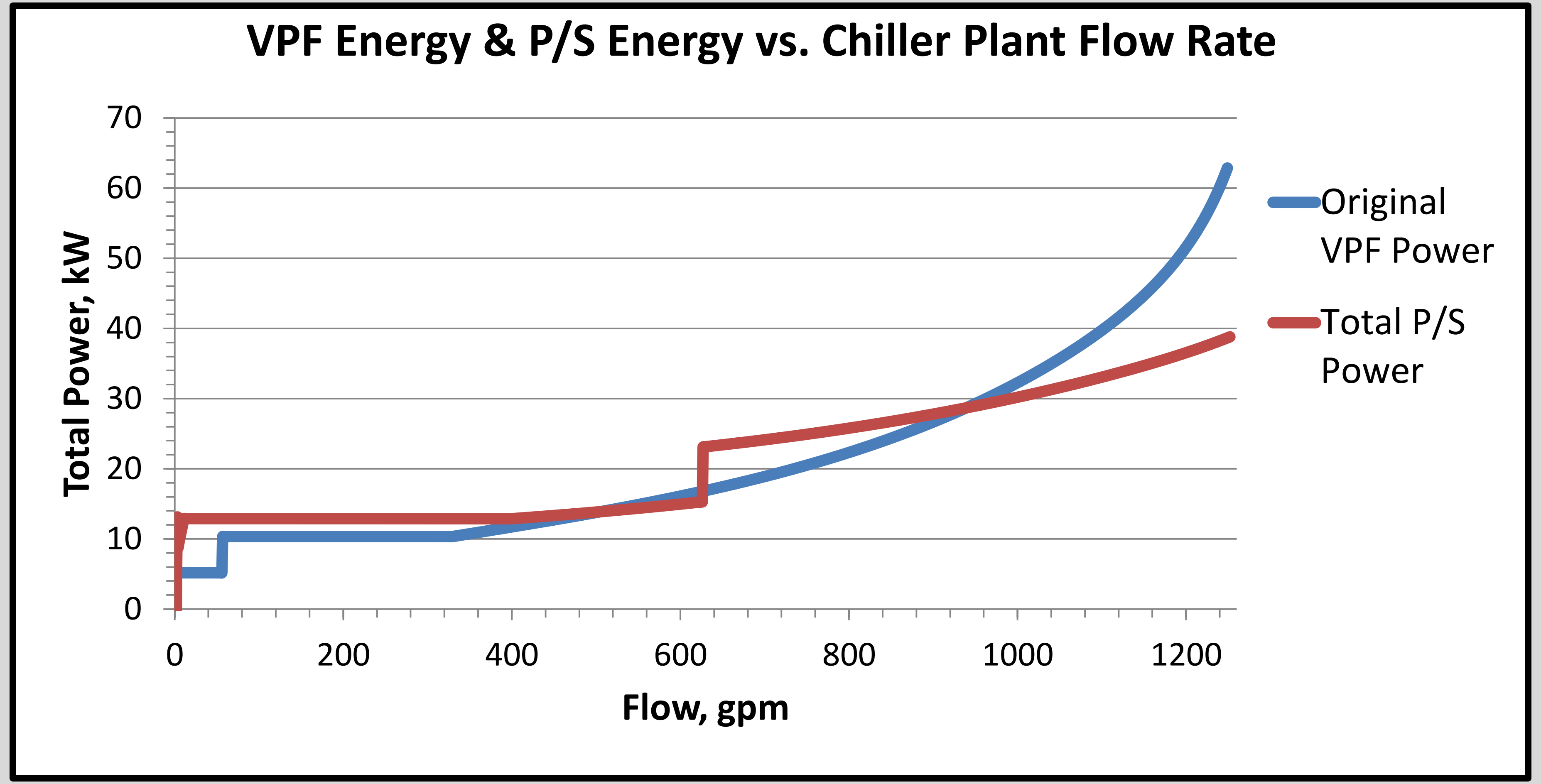
Variable Primary Flow System (MAE)

Variable Primary Flow System

- **Secondary Pumps – Bell & Gossett 1510-3G**
  - (2) Duty Pumps + (1) Standby Pump
    - $H_{secondary} = f(Q_{Actual}, N_{Actual})$
    - $P_{Nameplate} = 30$ HP
    - $Q_{Design} = 625$ GPM
    - $\eta_{Secondary\ Pump} = f(Q_{Actual}, N_{Actual})$
    - $\eta_{Motor} = f(P_{Shaft}, P_{Nameplate})$
    - $\eta_{VFD} = f(N_{Actual}, N_{Secondary})$
    - $H_{system} = H_{fixed} + [H_{Design} + H_{fixed}][Q_{Actual}/Q_{Design}]$
    - $WHP = (Q_{Actual} \times H_{System})/(3960 \times \eta_{Secondary})$
    - $kW = 0.746 \times WHP/(\eta_{Motor})$



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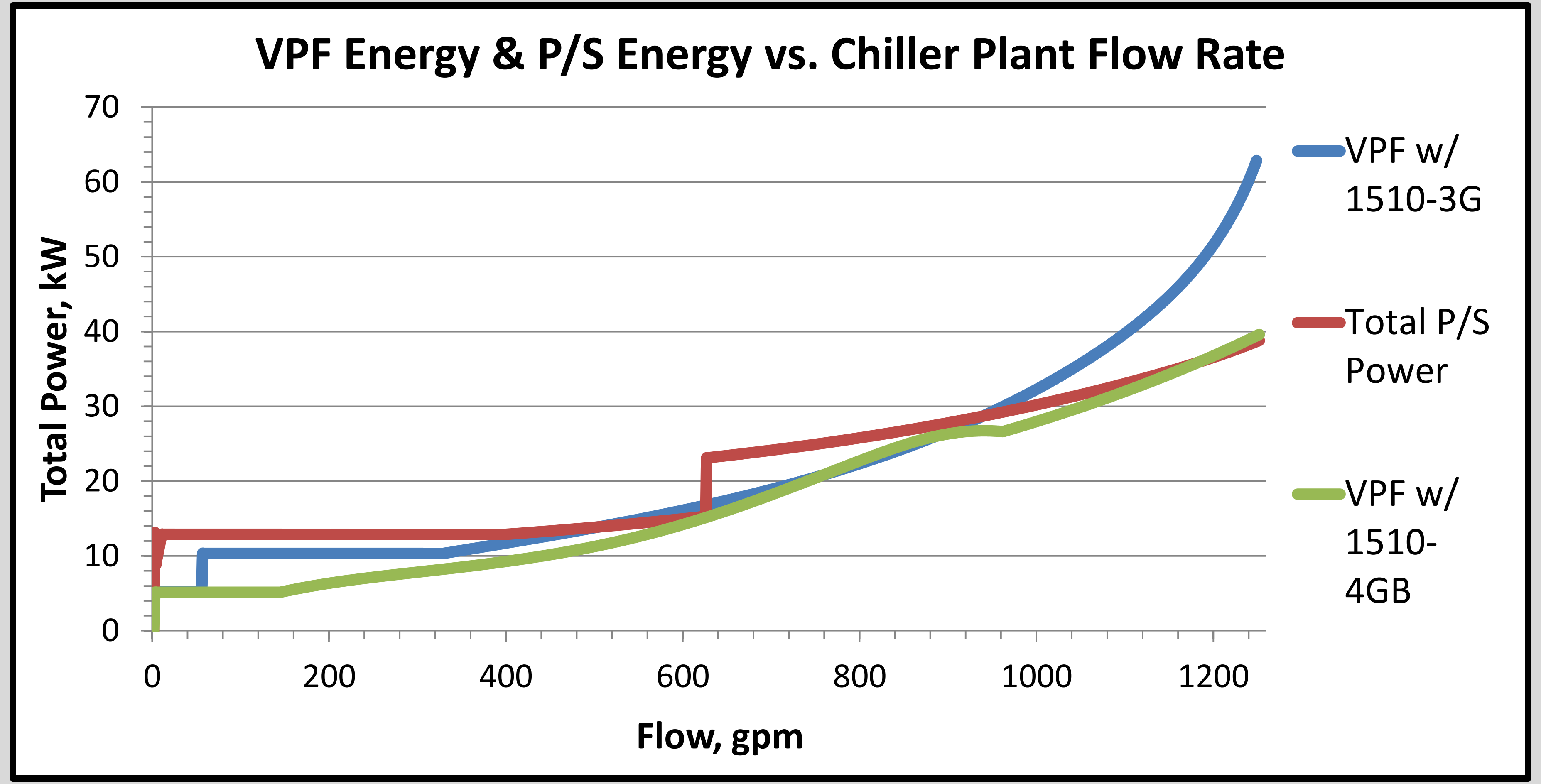
Variable Primary Flow System (MAE)

Variable Primary Flow System

- **Secondary Pumps – Bell & Gossett 1510-4GB**
  - B&G 1510-3G
    - 30HP Motor
    - $\eta_{\text{Design Flow}} = 68\%$
    - $\eta_{\text{150 GPM}} = 45\%$
  - B&G 1510-4GB
    - 25HP Motor
    - $\eta_{\text{Design Flow}} = 80\%$
    - $\eta_{\text{150 GPM}} = 58\%$



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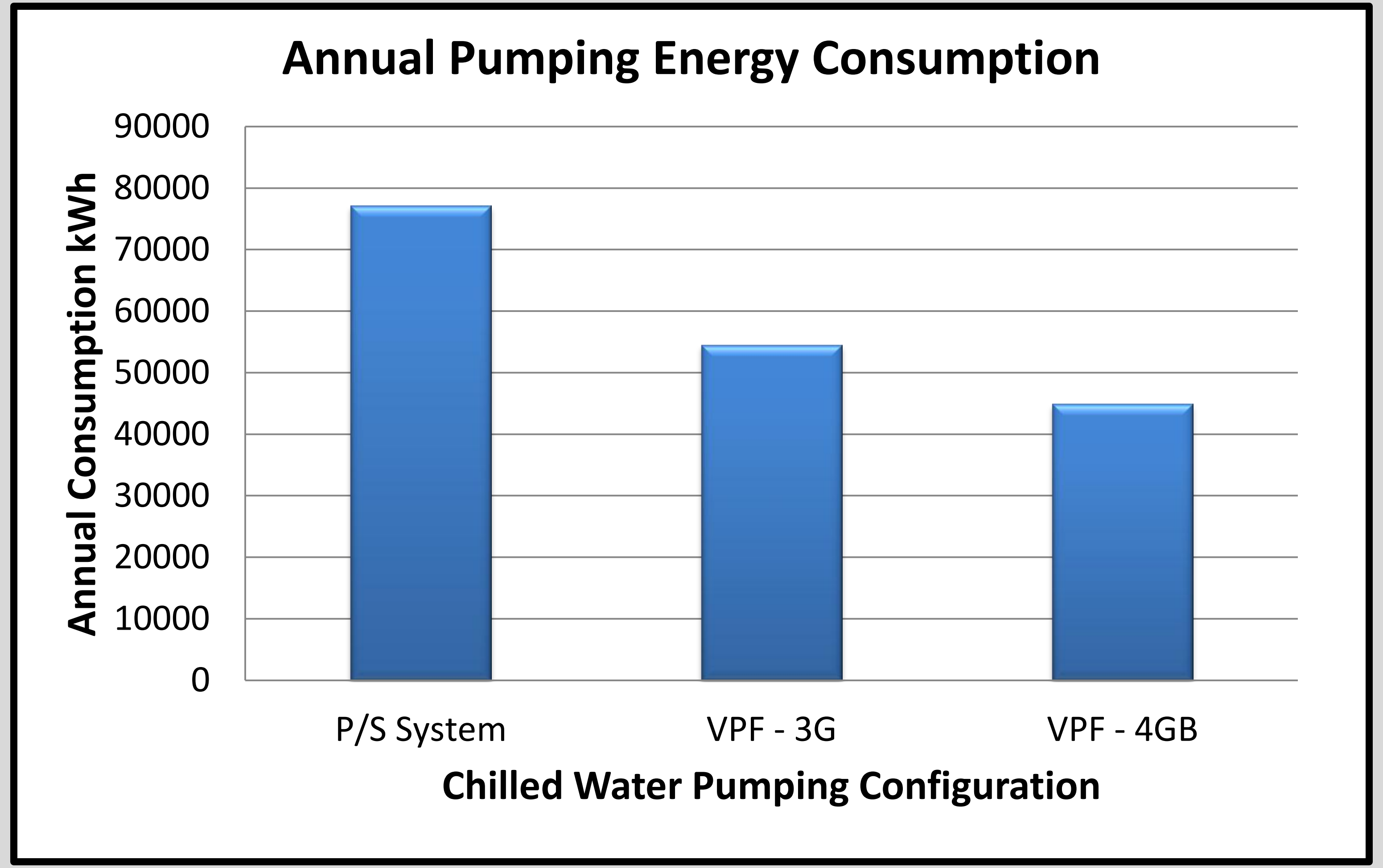
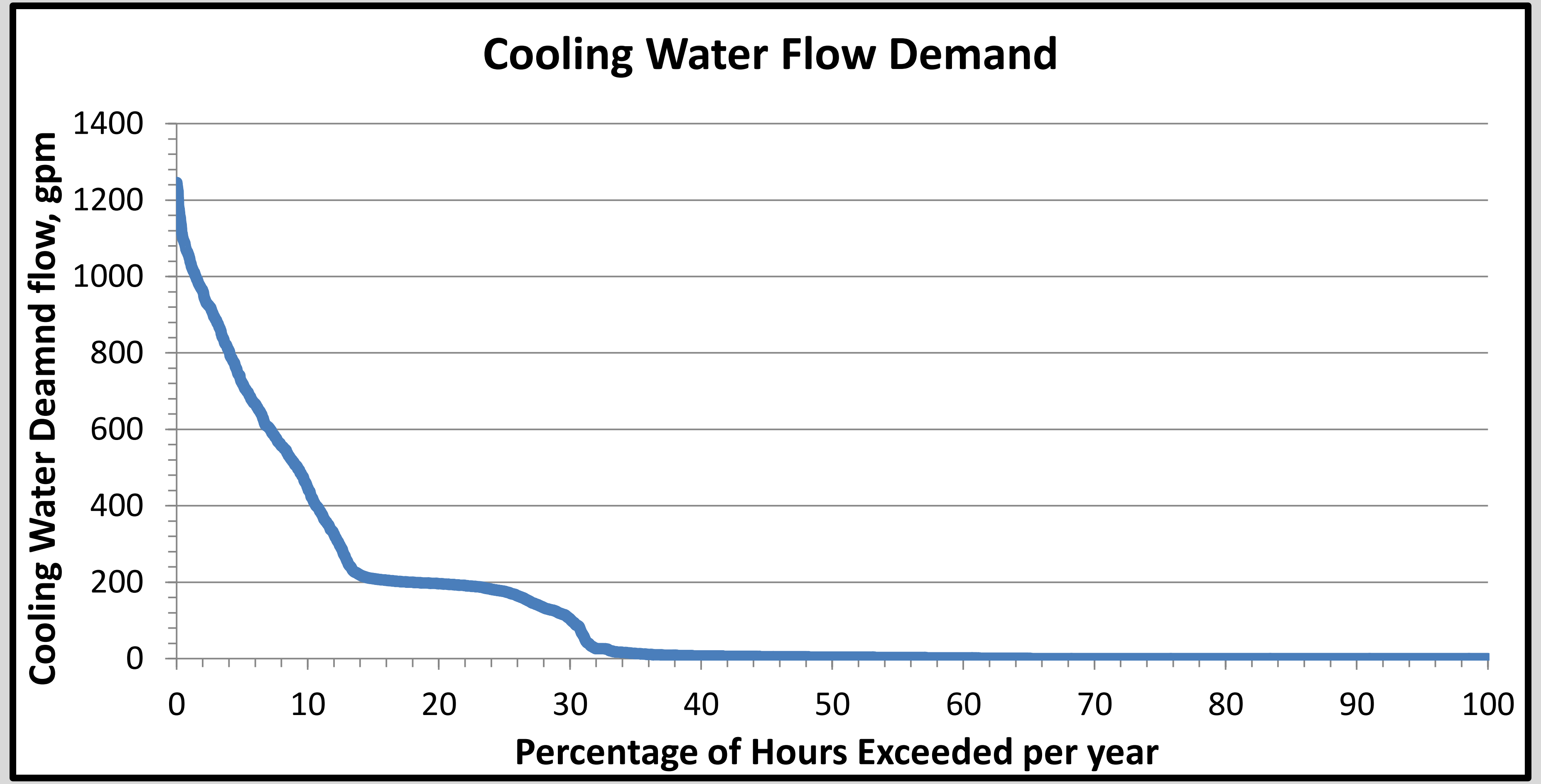
Variable Primary Flow System (MAE)

VPF vs. P/S Energy Consumption





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Variable Primary Flow System (MAE)

- **VPF vs. P/S Cost Analysis**
  - Lower First Cost – 3 Fewer Pumps
  - Larger VFD Replacement costs
  - Lower Electricity Costs
  - 30-Year Cost Savings of $46,069.00

30-Year Life Cycle Cost Breakdown

LCC 30-year Net Present Value	Primary/Secondary	VPF [1510-4GB]
Capital Costs	$70,725	$51,050
Overhauls	$8,966	$14,671
Maintenance	$20,383	$20,383
Electricity Consumption	$76,806	$44,707
Total 30-year Life Cycle Cost	$176,880	$130,811
	30-year Savings	$46,069

Annual Consumption Cost

	P/S System	VPF - 3G	VPF - 4GB
Annual Consumption (kWh)	77154.67	54529	44910
Savings over P/S (kWh)	-	22626	32245
Savings Over P/S	-	29%	42%
Total Plant Savings	-	2.78%	3.97%
Annual Consumption Cost	$3,718.86	$2,628.30	$2,164.66
Annual Dollar Savings	-	$1,090.56	$1,554.20

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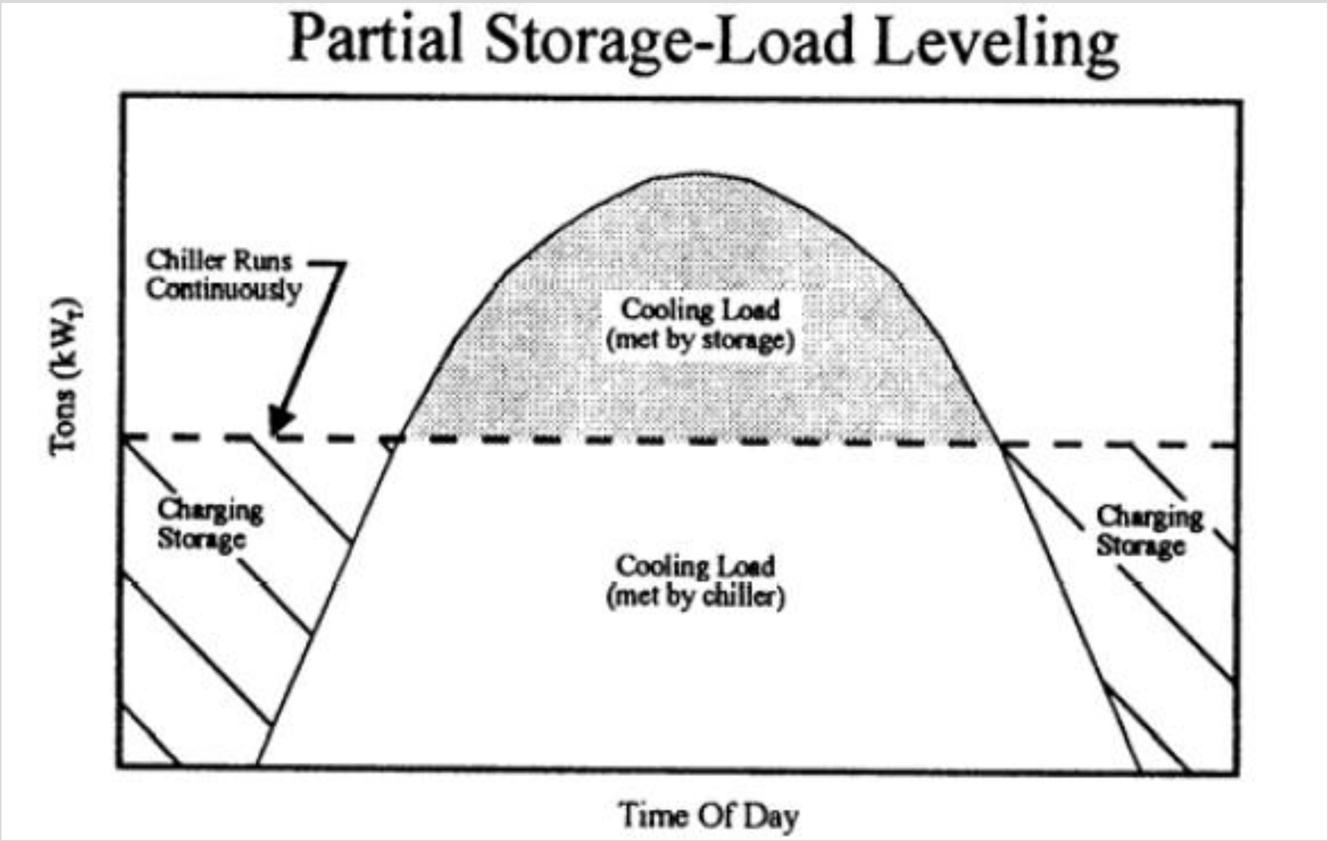
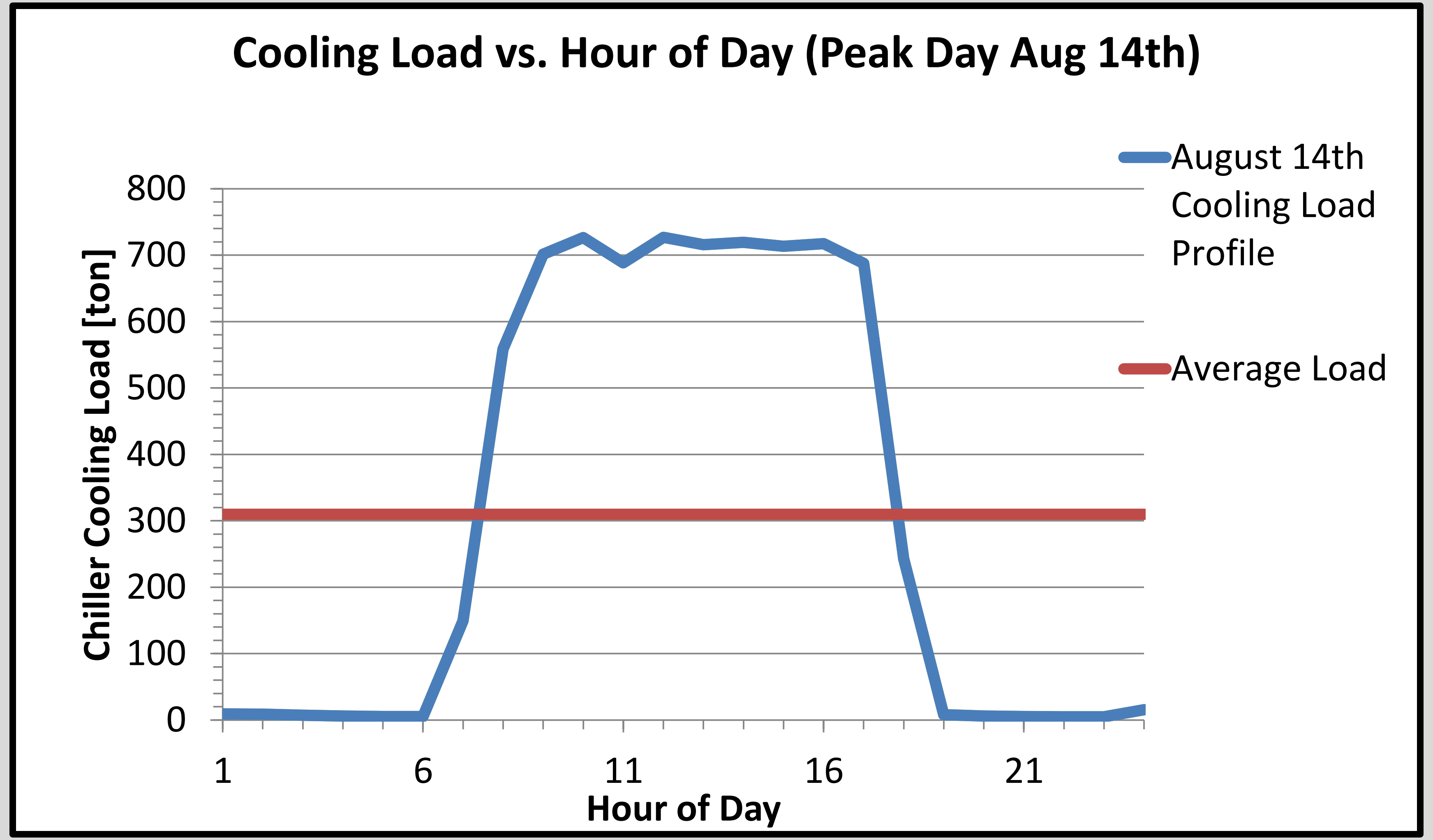
LATENT THERMAL STORAGE (MAE)

- **Immediate Benefits**
  - Smaller Chillers
  - Reduced Electrical Demand
  - Increased Short-Term Redundancy





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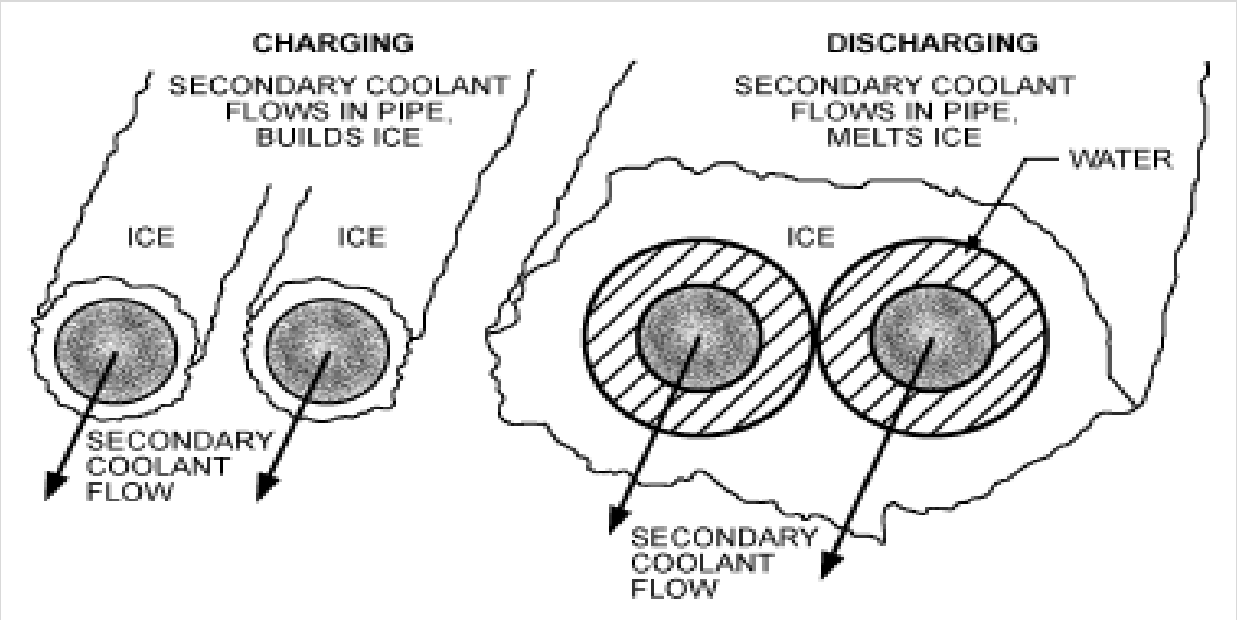
Latent Thermal Storage (MAE)

Latent (Ice) Storage

- Benefits –
  - High Capacity to Volume Ratio
  - Cost Effective for Smaller Systems
- Disadvantages –
  - Lower Chiller Efficiency & Capacity
  - Dynamic Heat Transfer Properties



Chiller Sizing

- **Original System**
  - 730-ton Peak Cooling Load
  - (2) 370-ton “Duty” Chillers
  - (1) 370-ton “Standby” Chiller
- **Ice Storage Chiller**
  - 400-ton Peak Cooling Load
  - (2) 200-ton “Duty” Chillers [130-ton Ice Capacity]
  - (1) 200-ton “Standby” Chiller [130-ton Ice Capacity]
  - 2900 ton-hour Storage System

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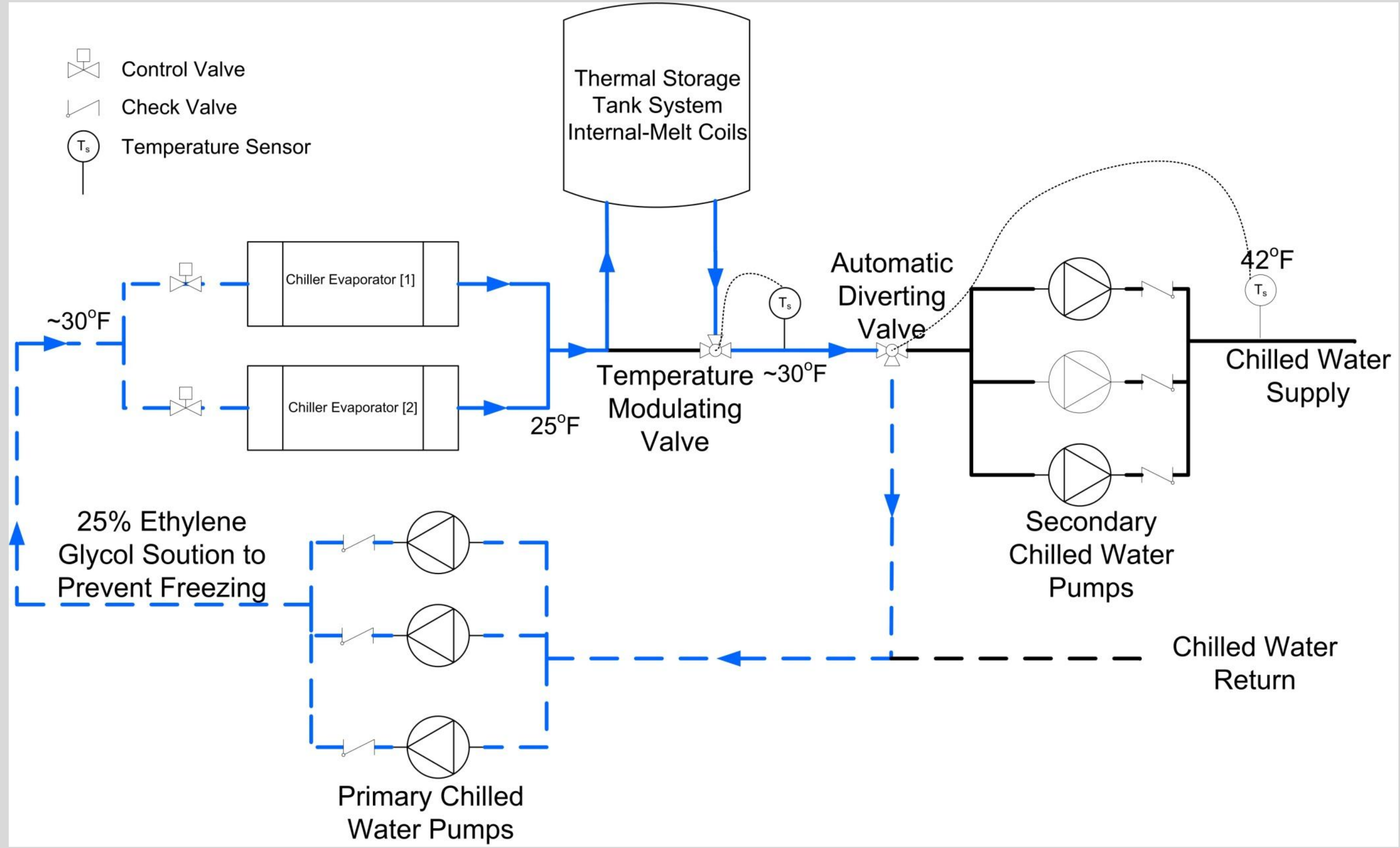
LATENT THERMAL STORAGE (MAE)

System Operation – "Charge" Mode

- Automatic Diverting Valve Sends Water to Bypass
- Chillers Operate at Low Temperature ~25°F
- 25% Glycol Solution goes to Storage Tanks
- Water in Tanks Freezes
- Water Returns to Primary Loop at ~30°F



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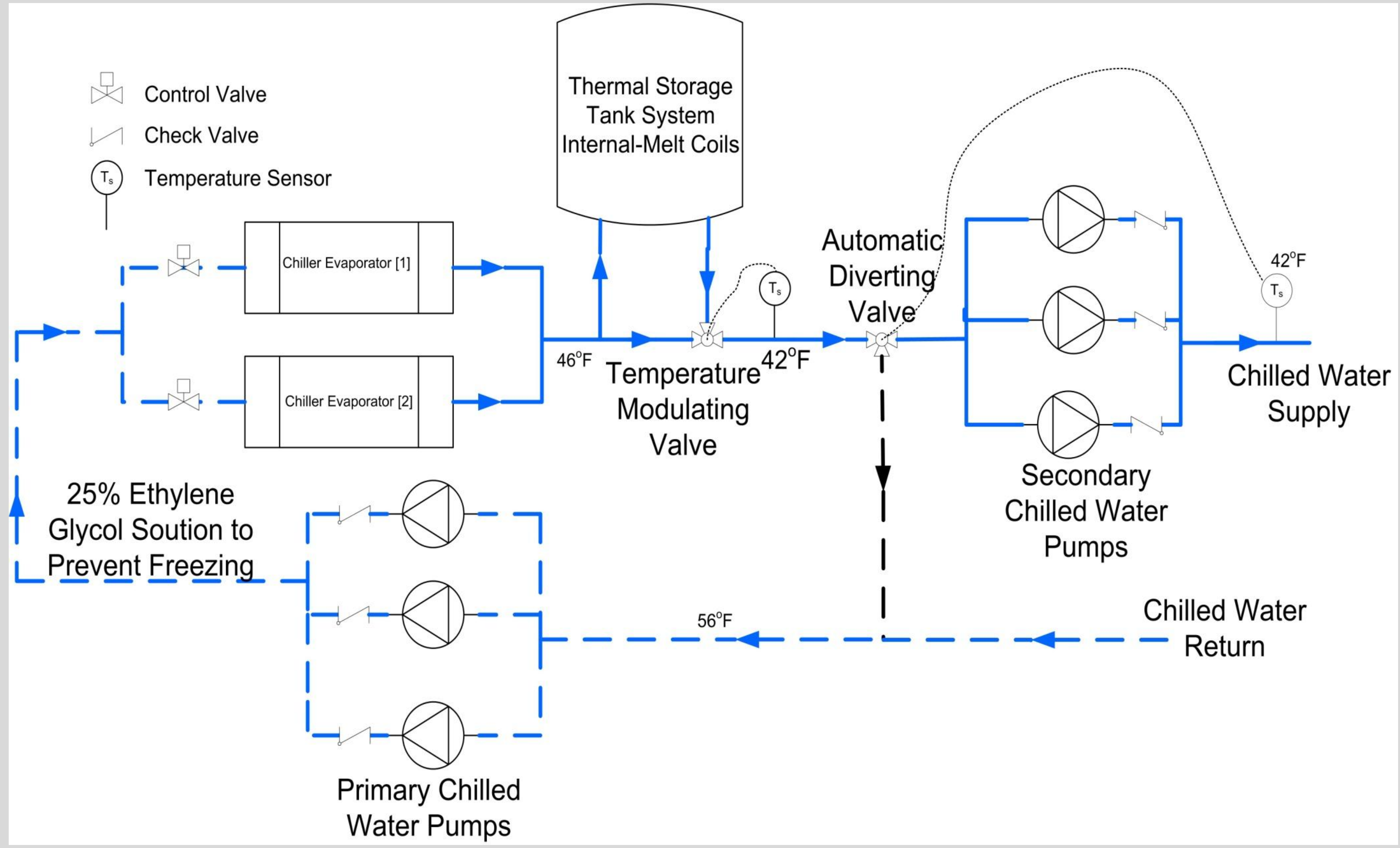
Latent Thermal Storage (MAE)

System Operation – "Discharge" Mode

- Automatic Diverting Valve Sends Water to Secondary
- Chillers Operate at Higher Temperature ~46°F
- 25% Glycol Solution goes to Storage Tanks
- Mixing Valve Regulates flow from Storage based on T_{CHWS}
- Diverting Valve Regulates flow through to Secondary



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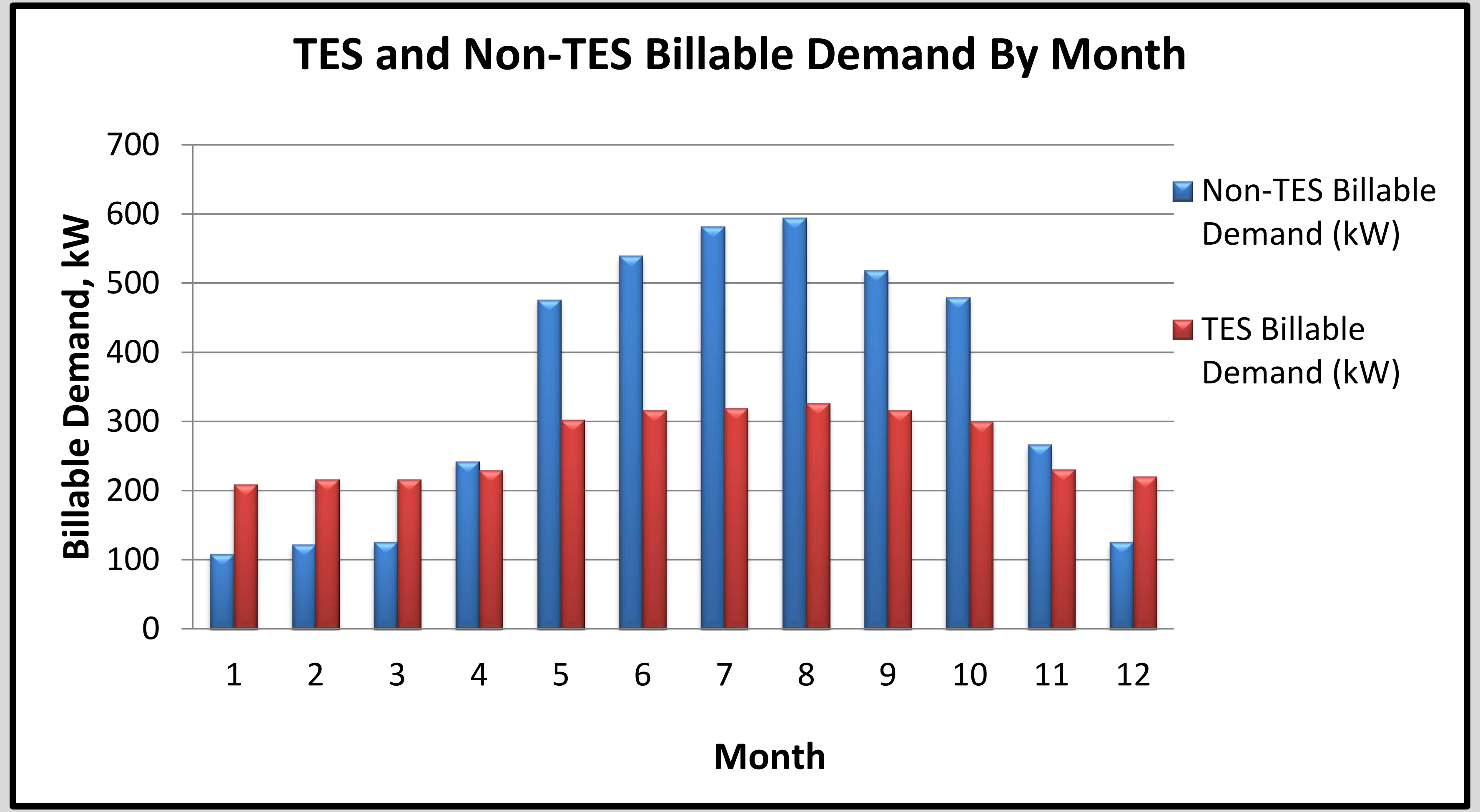
Latent Thermal Storage (MAE)

- **Energy Analysis**
- **Variables Include**
  - Wet Bulb Temperature (Night vs. Day)
  - Chiller Efficiency
  - Chiller Capacity
  - Discharge Strategy
    - Optimized
    - Storage Priority
    - Chiller Priority
  - Peak Daily Load
  - Daily ton-hours required
- Demand Reduction
- Consumption Increase



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LATENT THERMAL STORAGE (MAE)

- **Energy Analysis Results**
  - **Demand [kW]**
    - Lower Demand Charges During Cooling Months
    - Higher Demand During Winter
      - Would not Operate Storage during Winter
  - **Consumption [kWh]**
    - Annual Increase of 22%
    - Ice Efficiency Penalty
    - Not Offset by Lower Nighttime T_{WB}

Energy Consumption [kWh]		
	Original Energy Consumption	TES Electricity Consumption
Annual Energy Consumption	685,734 kWh	875,578 kWh
Increase Over Original	-	189,844kWh
Consumption Costs	$33,052.36	$42,202.85
Net Loss		$9150.49

Monthly Demand Charges	Non Storage		Storage	
	kW	Demand Fee	kW	Demand Fee
January	108.4	$972.35	208	$1,865.76
February	121.8	$1,092.55	216	$1,937.52
March	125.7	$1,127.53	216	$1,937.52
April	242.1	$2,171.64	229.2	$2,055.92
May	476	$4,269.72	302.4	$2,712.53
June	539.6	$4,840.21	316.4	$2,838.11
July	582	$5,220.54	319.4	$2,865.02
August	594.8	$5,335.36	326.8	$2,931.40
September	518.4	$4,650.05	316.4	$2,838.11
October	479.5	$4,301.12	299.9	$2,690.10
November	266.5	$2,390.51	230.8	$2,070.28
December	125.6	$1,126.63	22.4	$200.93
Annual Billing Demand kW	4180.4	$37,498.19	2795.7	$26,943.19
Net Benefit			1384.7	$10,555.00

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Latent Thermal Storage (MAE)

- **Cost Analysis**
  - $1400.00 per year Savings on Energy Bills
  - Lower Initial Cost Due to Chiller Plant
  - Reduced Chiller Maintenance
  - Very Low Storage System Maintenance
  - 30-Year Savings $448,152.00

30-Year Life Cycle Cost Breakdown		
LCC 30-year Net Present Value	Non-Storage	Thermal Storage
Capital Costs	$1,642,500	$1,427,184
Maintenance	$509,572	$305,743
Electricity Costs	$1,457,096	$1,428,088
Total 30-year Life Cycle Cost	$3,609,168	$3,161,016
Total 30-year Savings		$448,152

First Cost		
	Original System	TES
Chiller Plant	$1,642,500.00	$900,000.00
Tanks (Includes Slab, Glycol, Controls, Local Piping	$0.00	$437,400.00
3-Way Valve	$0.00	$3,000.00
A/G Piping & Insulation	$0.00	$13,090.00
U/G Piping & Insulation	$0.00	$62,400.00
U/G Piping Excavation	$0.00	$936.00
U/G Piping Fill	$0.00	$982.80
Concrete Pad Excavation (4-foot tank burial)	$0.00	$2,755.50
Privacy Fence	$0.00	$6,620.00
Total First Cost	$ 1,642,500.00	$ 1,427,184.30

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Solar Photovoltaic System – Electrical Depth

- **System Parameters**
  - 80 kW
  - 10° Fixed Tilt
  - (348) BP3230T Panels
  - 77% DC to AC Efficiency

10° Fixed Tilt NREL Data			
Month	Peak Sun Hours (kWh/m^2-day)	Days/ month	kWh/ month
1	2.41	31	4604
2	3.18	28	5488
3	4.65	31	8884
4	5.26	30	9725
5	5.98	31	11425
6	6.36	30	11759
7	6.02	31	11502
8	5.67	31	10833
9	4.91	30	9078
10	3.8	31	7260
11	2.6	30	4807
12	2.18	31	4165
Year	4.42	365	99429

Component	De-Rate Value
PV Module Nameplate DC Rating	95%
Inverter and Transformer	97%
Mismatch	98%
Diodes and Connections	100%
DC Wiring	98%
AC Wiring	99%
Soiling	95%
System Availability	98%
Shading	100%
Sun Tracking	100%
Age	95%
Overall De-Rate Factor	77%

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SOLAR PHOTOVOLTAIC SYSTEM – ELECTRICAL DEPTH

- **Financial Incentives**
  - **MACRS (Modified Accelerated cost Recovery System) Depreciation Tax Deductions -** $123,885.00

MACRS (Modified Accelerated Cost Recovery System) Depreciation Tax Deductions		
Depreciation Year	Net System Cost	$393,288.00
2011	10.00%	$13,765.08
2012	32.00%	$44,048.26
2013	19.20%	$26,428.95
2014	11.52%	$15,857.37
2015	11.52%	$15,857.37
2016	5.76%	$7,928.69

  - **Federal Renewable Energy Production Incentive (REPI)**
    - $0.013/kWh (Adjusted 1993 USD) for first 10 years
    - Approximately $2,500/year x 10 years = $25,000

- **Pennsylvania Sunshine Solar Rebate Program**

Pennsylvania Sunshine Solar Rebate Program		
	Rebate $/kW	Rebate Amount
First 10kW	$0.75	$ 7,500.00
Next 70kW	$0.50	$ 35,000.00
	Total	$ 42,500.00

- **Pennsylvania Public Utilities Commission – Solar Alternative Energy Credits (SEAC)**
  - Up to $39,772.00 Annually
- **Federal Energy Investment Tax Credit (ITC)**
  - 30% of Initial Investment
  - $191,000.00

Presentation Outline

- Building Information
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- Building Energy Consumption
- Re-Design Goals
- Mechanical Upgrades
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  - Latent Thermal Storage (MAE)
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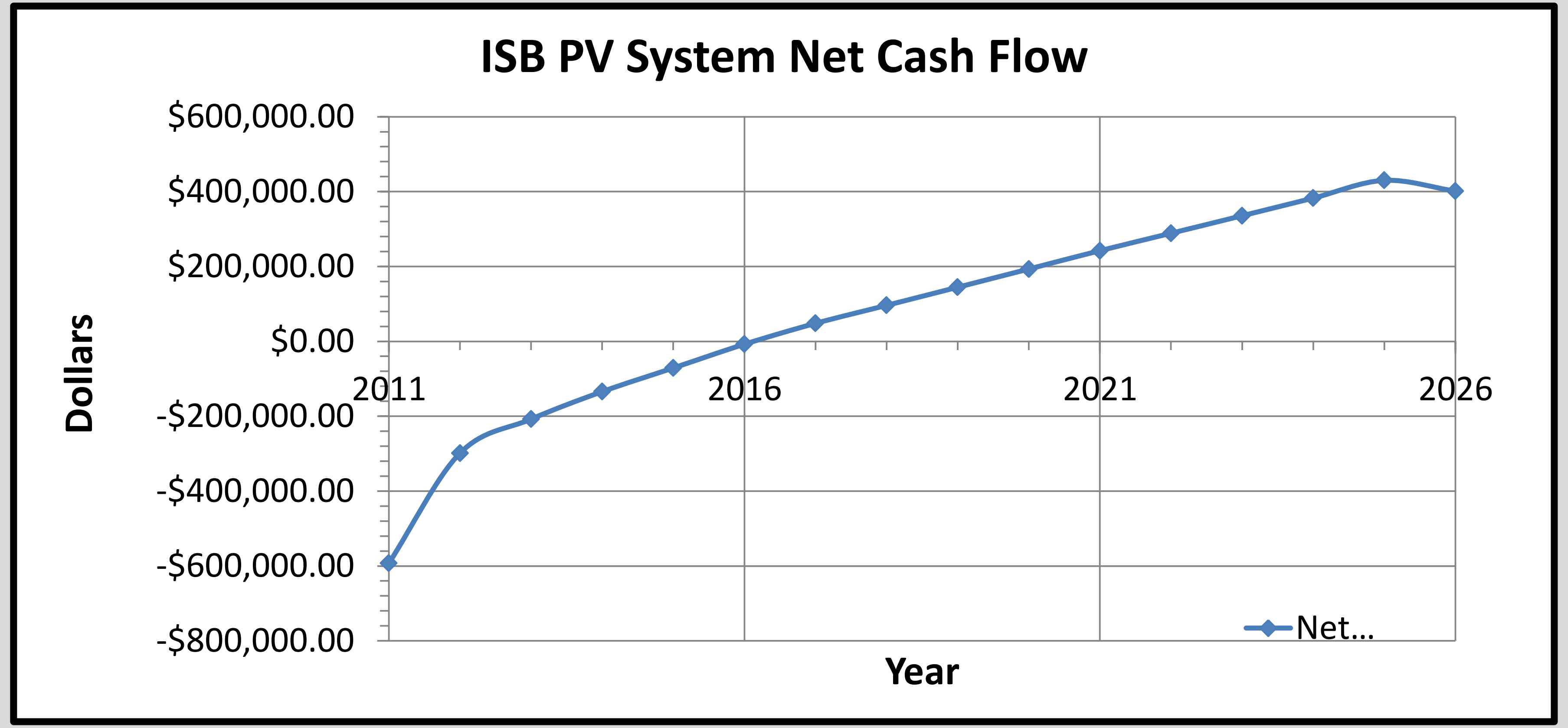
Solar Photovoltaic System – Electrical Depth

- **System Cost Estimate**
  - **Panel Cost**
    - $680.00 per Module x 348 Modules = $236,400.00
  - **Installation Cost**
    - $5.00 per Watt x 80,000 Watts = $400,200.00
  - **Total System Cost**
    - $636,840.00
- **Total Payback Period**
  - 5 Years
- **Total 15-Year Benefit**
  - $401,248.71



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Summary & Conclusion

- **Variable Primary Flow System**
  - **Saves $1,554.00 Annually**
  - **Lower Capital Cost**
  - **30-Year LCC Reduction of $46,069.00**
  - **Decreases Electrical Consumption & Emissions**
- **Latent Thermal Storage System**
  - **Saves $1404.51 Annually**
  - **Lower Capital Cost**
  - **30-Year LCC Reduction of $448,152.00**
  - **Increases Electrical Consumption & Emissions**
- **Solar Photovoltaic System**
  - **5-Year Payback Period**
  - **15-Year LCC Return of $401,248.00**
  - **Decreases Electrical Consumption & Emissions**

Annual Emissions for Electrical Consumption			
Pollutant	VPF Emissions Savings Per Year (lb)	Solar PV Emissions Savings Per Year (lb)	Latent Thermal Storage Increase per Year (lb)
Electric Use	32245 kWh	99429 kWh	189844 kWh
CO_{2e}	56106	173006	330329
CO_2	52881	163064	311344
CH_4	116	357	682
N_2O	1	4	7
NO_x	97	298	570
SO_x	276	852	1627
CO	28	85	162
TNMOC	2	7	14
Lead	0	0	0
Mercury	0	0	0
PM10	3	9	18
Solid Waste	6610	20383	38918

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Thank You

Questions & Comments