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
**BUILDING INFORMATION**

**Project Information**

- **Size**: 133,847 Square Feet
- **Stories**: 5 Stories Above Grade
- **Level**: 6th-Level Mechanical Penthouse
- **Basement**: Partial Basement
- **Occupancy**: Educational & Research Laboratory
- **Cost**: $52.1 million
- **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- **Owner**: Information not for Publication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**: Crosse 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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• 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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• 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
### Building Energy Consumption

<table>
<thead>
<tr>
<th>Function</th>
<th>Electricity (kWh)</th>
<th>Steam (kBtu)</th>
<th>kBtu/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Heating</td>
<td>-</td>
<td>4,537,606</td>
<td>4548466</td>
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<tr>
<td>Chiller Energy</td>
<td>349,031</td>
<td>-</td>
<td>1191243</td>
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<tr>
<td>Cooling Tower</td>
<td>121,524</td>
<td>-</td>
<td>414761</td>
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<tr>
<td>Condenser Pump</td>
<td>147,250</td>
<td>-</td>
<td>502564</td>
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<tr>
<td>HVAC Fans</td>
<td>561,366</td>
<td>-</td>
<td>191542</td>
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<tr>
<td>HVAC Pumps</td>
<td>67,930</td>
<td>-</td>
<td>231845</td>
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<tr>
<td>Lighting</td>
<td>368,045</td>
<td>-</td>
<td>1256137</td>
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<tr>
<td>Receptacle Loads</td>
<td>1,375,321</td>
<td>-</td>
<td>4693970</td>
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<tr>
<td><strong>Total Consumption</strong></td>
<td><strong>2,993,701</strong></td>
<td><strong>4,537,606</strong></td>
<td><strong>14755108</strong></td>
</tr>
</tbody>
</table>

### Annual Building Energy Consumption

- **Primary Heating**: 31%
- **Chiller Energy**: 8%
- **Cooling Tower**: 3%
- **Condenser Pump**: 3%
- **HVAC Fans**: 13%
- **HVAC Pumps**: 2%
- **Lighting**: 8%
- **Receptacle Loads**: 32%

- **Total Consumption**: 100%

---

**PRESENTATION OUTLINE**

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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
**VARIABLE PRIMARY FLOW SYSTEM (MAE)**

**Immediate Benefits**
- Fewer Pumps
- Less Pumping Energy
- Reduced Annual Electrical Consumption
- Low $\Delta T$ Tolerance

**Drawbacks**
- Control Stability & Reliability
- Open Loop Control Based on Inlet temperature
- Variable Flow Chiller Capability
- New Chillers can Handle $\Delta V$
- Typically Overhyped
- Proven with Parametric Study
Original Primary/Secondary System

• Primary Pumps – Bell & Gossett 1510-3BC
  ▪ (2) Duty Pumps + (1) Standby Pump
  ▪ 50 ft Head
  ▪ 15 HP
  ▪ 625 GPM
  ▪ $\eta_{\text{Primary Pump}} = 73\%$
  ▪ $\eta_{\text{Motor}} = 95\%$

$WHP = \frac{(Q \times H)}{(3960 \times \eta_{\text{Primary}})}$

$kW = 0.746 \times \frac{WHP}{\eta_{\text{Motor}}} = 8.5kW$
Original Primary/Secondary System

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

**Variable Primary Flow System**

- **Secondary Pumps** – Bell & Gossett 1510-3G
  - (2) Duty Pumps + (1) Standby Pump
  - \( H_{\text{system}} = H_{\text{fixed}} + \left[ H_{\text{Design}} + H_{\text{fixed}} \right] \frac{Q_{\text{Actual}}}{Q_{\text{Design}}} \)
  - \( H_{\text{primary}} = H_{\text{fixed}} + \left[ H_{\text{Design}} + H_{\text{fixed}} \right] \frac{Q_{\text{Actual}}}{Q_{\text{Design}}} \)
  - \( W_{\text{HP}} = \frac{Q_{\text{Actual}} \times H_{\text{System}}}{3960 \times \eta_{\text{Secondary}}} \)
  - \( kW = 0.746 \times W_{\text{HP}} \div \eta_{\text{Motor}} \)
Variable Primary Flow System

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

- **Bell & Gossett 1510-3G**
  - 25HP Motor
  - $\eta_{\text{Design Flow}} = 80\%$
  - $\eta_{150 \text{ GPM}} = 58\%$

- **B&G 1510-4GB**

- **B&G 1510-3G**

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**PRESENTATION OUTLINE**

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Variable Primary Flow System (MAE)

VPF vs. P/S Energy Consumption

![Graph showing annual consumption kWh for P/S System, VPF - 3G, and VPF - 4GB.]

Chilled Water Pumping Configuration

![Graph showing percentage of hours exceeded per year.]

Cooling Water Flow Demand

- Building Information
- Existing Mechanical Systems
- Building 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

#### Annual Consumption Cost Breakdown

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

#### 30-Year Life Cycle Cost Breakdown

<table>
<thead>
<tr>
<th></th>
<th>Primary/Secondary</th>
<th>VPF (1510-4GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>$70,725</td>
<td>$51,050</td>
</tr>
<tr>
<td>Overhauls</td>
<td>$8,966</td>
<td>$14,671</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$20,383</td>
<td>$20,383</td>
</tr>
<tr>
<td>Electricity Consumption</td>
<td>$76,806</td>
<td>$44,707</td>
</tr>
<tr>
<td>Total 30-year Life Cycle Cost</td>
<td>$176,880</td>
<td>$130,811</td>
</tr>
</tbody>
</table>

30-year Savings: $46,069.00
PRESENTATION OUTLINE
- Building Information
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LATENT THERMAL STORAGE (MAE)
- Immediate Benefits
  - Smaller Chillers
  - Reduced Electrical Demand
  - Increased Short-Term Redundancy

Cooling Load vs. Hour of Day (Peak Day Aug 14th)

Partial Storage-Load Leveling

Chiller Cooling Load [ton]
Hour of Day
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

[Diagram showing system operation and components]
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
**PRESENTATION OUTLINE**

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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**

**Chart: TES and Non-TES Billable Demand By Month**

- **TES Billable Demand (kW)**
- **Non-TES Billable Demand (kW)**

**Line Graph: TES and Non-TES Billable Demand By Month**

- **X-axis:** Month
- **Y-axis:** Billable Demand, kW
### 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 $T_{WB}$

---

**Latent Thermal Storage (MAE)**

<table>
<thead>
<tr>
<th>Month</th>
<th>Non Storage kW</th>
<th>Non Storage Demand Fee</th>
<th>Storage kW</th>
<th>Storage Demand Fee</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>108.4</td>
<td>$972.35</td>
<td>208</td>
<td>$1,865.76</td>
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<tr>
<td>February</td>
<td>121.8</td>
<td>$1,092.55</td>
<td>216</td>
<td>$1,937.52</td>
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<tr>
<td>March</td>
<td>125.7</td>
<td>$1,127.53</td>
<td>216</td>
<td>$1,937.52</td>
</tr>
<tr>
<td>April</td>
<td>242.1</td>
<td>$2,171.64</td>
<td>229.2</td>
<td>$2,015.92</td>
</tr>
<tr>
<td>May</td>
<td>476.0</td>
<td>$4,269.32</td>
<td>302.4</td>
<td>$2,712.53</td>
</tr>
<tr>
<td>June</td>
<td>539.6</td>
<td>$4,840.21</td>
<td>316.4</td>
<td>$2,838.11</td>
</tr>
<tr>
<td>July</td>
<td>582.0</td>
<td>$5,220.54</td>
<td>319.4</td>
<td>$2,865.02</td>
</tr>
<tr>
<td>August</td>
<td>594.8</td>
<td>$5,335.36</td>
<td>326.8</td>
<td>$2,931.40</td>
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<tr>
<td>September</td>
<td>518.4</td>
<td>$4,650.05</td>
<td>316.4</td>
<td>$2,838.11</td>
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<tr>
<td>October</td>
<td>479.5</td>
<td>$4,301.12</td>
<td>299.9</td>
<td>$2,690.10</td>
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<tr>
<td>November</td>
<td>266.5</td>
<td>$2,390.51</td>
<td>230.3</td>
<td>$2,070.28</td>
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<tr>
<td>December</td>
<td>125.6</td>
<td>$1,126.63</td>
<td>22.4</td>
<td>$200.93</td>
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</tbody>
</table>

**Annual Billing Demand kW**

<table>
<thead>
<tr>
<th>Month</th>
<th>Non Storage</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4180.4</td>
<td>2795.7</td>
</tr>
<tr>
<td>July</td>
<td>37,498.19</td>
<td>26,943.19</td>
</tr>
<tr>
<td>October</td>
<td>2795.7</td>
<td>299.9</td>
</tr>
<tr>
<td>June</td>
<td>37,498.19</td>
<td>316.4</td>
</tr>
<tr>
<td>March</td>
<td>4180.4</td>
<td>2795.7</td>
</tr>
<tr>
<td>November</td>
<td>2795.7</td>
<td>230.3</td>
</tr>
<tr>
<td>December</td>
<td>37,498.19</td>
<td>22.4</td>
</tr>
<tr>
<td>Annual</td>
<td>26,943.19</td>
<td>22.4</td>
</tr>
</tbody>
</table>

**Energy Consumption [kWh]**

<table>
<thead>
<tr>
<th>Category</th>
<th>Original Energy Consumption</th>
<th>TES Electricity Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Energy Consumption</td>
<td>685,734 kWh</td>
<td>875,578 kWh</td>
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<tr>
<td>Increase Over Original</td>
<td>189,844 kWh</td>
<td></td>
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<tr>
<td>Consumption Costs</td>
<td>$33,052.36</td>
<td>$42,202.85</td>
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<tr>
<td>Net Loss</td>
<td>$9150.49</td>
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</table>

**Net Benefit**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Benefit</td>
<td>$10,555.00</td>
</tr>
</tbody>
</table>

---

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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

<table>
<thead>
<tr>
<th></th>
<th>Original System</th>
<th>TES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiller Plant</td>
<td>$1,642,500.00</td>
<td>$800,000.00</td>
</tr>
<tr>
<td>Tanks (Includes Slab, Glycol, Controls, Local Piping)</td>
<td>$0.00</td>
<td>$437,400.00</td>
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<tr>
<td>3-Way Valve</td>
<td>$0.00</td>
<td>$3,000.00</td>
</tr>
<tr>
<td>A/G Piping &amp; Insulation</td>
<td>$0.00</td>
<td>$13,090.00</td>
</tr>
<tr>
<td>U/G Piping &amp; Insulation</td>
<td>$0.00</td>
<td>$62,400.00</td>
</tr>
<tr>
<td>U/G Piping Excavation</td>
<td>$0.00</td>
<td>$936.00</td>
</tr>
<tr>
<td>U/G Piping Fill</td>
<td>$0.00</td>
<td>$982.80</td>
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<tr>
<td>Concrete Pad Excavation (4-foot tank burial)</td>
<td>$0.00</td>
<td>$2,755.50</td>
</tr>
<tr>
<td>Privacy Fence</td>
<td>$0.00</td>
<td>$6,620.00</td>
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<tr>
<td><strong>Total First Cost</strong></td>
<td>$1,642,500.00</td>
<td>$1,427,184.30</td>
</tr>
</tbody>
</table>

30-Year Life Cycle Cost Breakdown

<table>
<thead>
<tr>
<th></th>
<th>Non-Storage</th>
<th>Thermal Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>$1,642,500</td>
<td>$3,427,184</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$509,572</td>
<td>$305,743</td>
</tr>
<tr>
<td>Electricity Costs</td>
<td>$1,457,096</td>
<td>$1,428,088</td>
</tr>
<tr>
<td><strong>Total 30-Year Life Cycle Cost</strong></td>
<td>$3,609,168</td>
<td>$3,161,016</td>
</tr>
<tr>
<td><strong>Total 30-years Savings</strong></td>
<td>$448,152</td>
<td></td>
</tr>
</tbody>
</table>
**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**

<table>
<thead>
<tr>
<th>Month</th>
<th>Peak Sun Hours (kWh/m²-day)</th>
<th>Days/month</th>
<th>kWh/month</th>
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<td>2.41</td>
<td>31</td>
<td>4604</td>
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<td>9725</td>
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<td>5.98</td>
<td>31</td>
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<td>12</td>
<td>2.18</td>
<td>31</td>
<td>4165</td>
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</table>

**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%**
Financial Incentives

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

- **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

**MACRS (Modified Accelerated Cost Recovery System) Depreciation Tax Deductions**

<table>
<thead>
<tr>
<th>Depreciation Year</th>
<th>Net System Cost</th>
<th>MACRS Depreciation Tax Deduction</th>
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</thead>
<tbody>
<tr>
<td>2011</td>
<td>$13,765.08</td>
<td>$393,288.00</td>
</tr>
<tr>
<td>2012</td>
<td>$44,048.26</td>
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<tr>
<td>2013</td>
<td>$26,428.95</td>
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<tr>
<td>2014</td>
<td>$15,857.37</td>
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<tr>
<td>2015</td>
<td>$15,857.37</td>
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<tr>
<td>2016</td>
<td>$7,928.69</td>
<td></td>
</tr>
</tbody>
</table>

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

Building Information
- Existing Mechanical Systems
- Building Energy Consumption
- Re-Design Goals
- Mechanical Upgrades
- Variable Primary Flow (MAE)
- Latent Thermal Storage (MAE)

Electrical Breadth – Solar Photovoltaic System
- Conclusion & Summary
- Acknowledgements

**Solar Photovoltaic System – Electrical Depth**

**Pennsylvania Sunshine Solar Rebate Program**

<table>
<thead>
<tr>
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**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
**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
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

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>VPF Emissions Savings Per Year (lb)</th>
<th>Solar PV Emissions Savings Per Year (lb)</th>
<th>Latent Thermal Storage Increase per Year (lb)</th>
</tr>
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<tbody>
<tr>
<td>Electric Use</td>
<td>32245 kWh</td>
<td>99429 kWh</td>
<td>189844 kWh</td>
</tr>
<tr>
<td>CO₂</td>
<td>56106</td>
<td>173006</td>
<td>330329</td>
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<tr>
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<tr>
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<td>14</td>
</tr>
<tr>
<td>Lead</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Mercury</td>
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<td>0</td>
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<tr>
<td>PM10</td>
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<td>9</td>
<td>18</td>
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<tr>
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<td>20383</td>
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### Summary & Conclusion

- **Variable Primary Flow System**
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</tr>
</tbody>
</table>

**Additional Notes**

- Variable Primary Flow System saves $1,554.00 annually with lower capital cost and a 30-year LCC reduction of $46,069.00.
- Latent Thermal Storage System saves $1,404.51 annually with lower capital cost and a 30-year LCC reduction of $448,152.00.
- Solar Photovoltaic System has a 5-year payback period with a 15-year LCC return of $401,248.00.
ACKNOWLEDGEMENTS

• Dr. William Bahnfleth, Faculty Advisor
• Dr. Jim Freihaut, Penn State AE Faculty
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• Scott Kincaid, Tozour Energy Services
• Turner Construction
• Amy Cavanaugh, Turner Construction
• Fellow AE Students
THANK YOU
QUESTIONS & COMMENTS