Redland Tech Center

Presentation Outline

- Project Overview
- Chilled Beam HVAC System (MAE) (Mechanical)
- NEC Wire Sizing (Electrical)
- Parking Garage Sequencing
- Conclusion and Recommendations
- Questions and Acknowledgements

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Project Overview

• Two office buildings with stand alone parking garage
  • Building II: 9 levels; 210,240 SF
  • Building III: 6 levels; 136,430 SF
  • Parking Garage: 6 levels; 310,600 SF
  • January 2008 – June 2009 Construction
  • $52,800,000 Negotiated GMP
  • Design-Bid-Build
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Project Overview

- Structural steel office buildings
- Precast façade with curtain wall and ribbon windows
- Self-contained air conditioning units with VAVs
- Precast parking garage
- LEED Silver Certification
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Critical Industry Research: Chilled Beams
- Energy efficiency becoming more important
- Water more efficient energy transporter
- Reduce ductwork, fans, AHUs, VAVs, plenum space
- Increase piping, pumping
- Two types: Passive and Active
- Used in Europe and Australia for several decades

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Passive Chilled Beams

- Use natural convection to cool air
- Only provide sensible cooling
- Cannot be used for heating
- Requires separate system for latent loads and ventilation
- 200-650 BTUH sensible heat per ft of beam
- Exposed or recessed type
Active Chilled Beams

- Forced air induction
- Primary air and secondary cooling
- Used for cooling and heating
- 1,100 BTUH sensible heat per ft of beam
- Typically used with dedicated outdoor air system (DOAS)
- Several varieties to suit building requirements
Multi-service Chilled Beams

- Prefabricated unit
- Incorporates other building systems
- Both passive and active types
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Chilled Beam Advantages

- Reduce primary air by 75-85%
- 20-40% savings in energy consumption
- Reduced ductwork size
- Low maintenance
- Increased room comfort; quiet
- Payback less than 5 years typical
Chilled Beam Disadvantages

- Initial cost higher
- Not familiar in United States
- Cannot be used in areas with high or unpredictable humidity levels
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Chilled Beam Applications
- Best for projects with high sensible loads
- Retrofit and renovation projects
- Projects with building height restrictions
- Projects with ultimate sustainability goals

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Chilled Beams at RTC Building II
- Analysis uses active chilled beams
- Used chilled beams only in open office space
- Maximized energy efficiency by matching primary air to ventilation air requirements
- Analysis assumptions:
  - 100 ft²/person
  - Current design used 72°F room air, 55°F supply air
  - Latent load = 200 BTUH/person

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Analysis assumptions:
- 100 ft²/person
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### Floor Description

<table>
<thead>
<tr>
<th>Floor</th>
<th>Description</th>
<th>Area (SF)</th>
<th>Population</th>
<th>VAV CFM</th>
<th>Sensible Load (BTUH)</th>
<th>Latent Load (BTUH)</th>
<th>chilled beams requirement (BTUH)</th>
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<tr>
<td>1</td>
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<td>2,823</td>
</tr>
</tbody>
</table>
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Number of Chilled Beams Required

- Room air: 72°F/50% relative humidity (0.00836 lbw/lbda)
- Supply air: 55°F/58% relative humidity (0.00535 lbw/lbda)
- Analysis used 1,000 BTUH sensible heat per ft of beam
- Based on 6’ chilled beams

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<table>
<thead>
<tr>
<th>Floor</th>
<th>Floor Load (BTUH)</th>
<th>Primary Air Sensible (BTUH)</th>
<th>Secondary Air Sensible (BTUH)</th>
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<td>8</td>
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<table>
<thead>
<tr>
<th>Floor</th>
<th>Secondary Ambient Temperature (BTUH)</th>
<th>Linear Feet of Chilled Beam Required (ft)</th>
<th>Number of 6’ Beams</th>
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<td>1</td>
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<td>160,379</td>
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<td>3</td>
<td>166,407</td>
<td>150</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>166,407</td>
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<td>166,407</td>
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<td>27</td>
</tr>
<tr>
<td>9</td>
<td>166,407</td>
<td>150</td>
<td>27</td>
</tr>
</tbody>
</table>

Total Number of 6’ Beams: 257
Chilled Beam Costs

- Material cost for chilled beams is $140 per linear foot
- Material cost for chilled beams is $140 per linear foot
- Each 6’ beam will cost $1,680 installed

<table>
<thead>
<tr>
<th>Floor</th>
<th>Number of 6’ Chilled Beams</th>
<th>Material Cost (Each)</th>
<th>Labor Cost (Each)</th>
<th>Total Cost (Each)</th>
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<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>$3,500</td>
<td>$1,500</td>
<td>$5,000</td>
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<tr>
<td>2</td>
<td>25</td>
<td>$3,500</td>
<td>$1,500</td>
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<tr>
<td>3</td>
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<td>8</td>
<td>25</td>
<td>$3,500</td>
<td>$1,500</td>
<td>$5,000</td>
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</tbody>
</table>

Total Chilled Beam Cost: $431,760
Chilled Beam Cost per SF: $2.47
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<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Material</th>
<th>Labor</th>
<th>Total</th>
<th>Percent</th>
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</thead>
<tbody>
<tr>
<td>Chilled Water Piping</td>
<td>$116,601</td>
<td>$66,159</td>
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<td>$182,760</td>
<td>7.6%</td>
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<tr>
<td>Mechanical Insulation</td>
<td>$58,998</td>
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<td>$135,000</td>
<td>5.6%</td>
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<tr>
<td>Pumps</td>
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<tr>
<td>Cooling Towers</td>
<td>$205,775</td>
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<td>$222,100</td>
<td>9.2%</td>
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<td>VAVs</td>
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<td>$7,413</td>
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<td>$86,513</td>
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<td>Self Contained AHUs</td>
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<td>Ductwork</td>
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<tr>
<td>Controls</td>
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<td>$135,000</td>
<td>5.6%</td>
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<tr>
<td>Condensate Piping</td>
<td>$9,412</td>
<td>$13,488</td>
<td></td>
<td>$22,900</td>
<td>1.0%</td>
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<tr>
<td>Testing and Balancing</td>
<td>$0</td>
<td>$18,000</td>
<td></td>
<td>$18,000</td>
<td>0.7%</td>
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<tr>
<td>Totals</td>
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<td>$903,382</td>
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<td>$2,404,560</td>
<td>100.0%</td>
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</tbody>
</table>

VAV Mechanical System Cost per SF = $11.44
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Chilled Beam Component Costs

- Chilled water piping
  - Material: $8.94/lf * 1,300lf/floor * 9 floors = $104,598
  - Labor: $5.06/lf * 1,300lf/floor * 9 floors = $59,202
  - Total Additional Cost: $163,800

- Mechanical Insulation
  - No change

- Pumps
  - Material: $20,004 * 2 = $40,008
  - Labor: $3,558 * 2 = $7,116
  - Total Additional Cost: $47,124

- Cooling Tower
  - No change
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Chilled Beam Component Costs
• VAVs
  • Material: 72 VAVs * $442/VAV = $31,824
  • Labor: 72 VAVs * $442/VAV = $31,824
  • Total Savings: $38,808
• Fans
  • Material: 0.7 * 0.92 * $79,100 = $50,940
  • Labor: 0.7 * 0.92 * $7,413 = $5,774
  • Total Savings: $55,714
• SCUs
  • Material: $790,242
  • Labor: $38,183
  • Total Savings: $828,425
• Electric Heating Coils
  • Material: 257 coils * $620/coil = $159,340
  • Labor: 257 coils * $59/coil = $15,163
  • Total Additional Cost: $174,503

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Chilled Beam Component Costs

• Wiring and Conduit for Heating Coils
  • Material: 3-wires*$0.81/LF*650LF/floor*9floors = $14,217
  • Labor: $2.47/LF*650LF/floor*9floors = $14,450
  • Total Additional Cost: $28,667

• Centrifugal Chillers
  • Material: $384,160
  • Labor: $384,160
  • Total Additional Cost: $402,192

• AHUs
  • Material: $46,592
  • Labor: $7,056
  • Total Additional Cost: $53,648

• Ductwork
  • Material: 0.45*0.92*$97,290 = $46,278
  • Labor: 0.25*0.92*$607,710 = $134,773
  • Total Savings: $179,051
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Chilled Beam Component Costs
• Controls
  • Material: 0.92*$86,670 = $79,736
  • Labor: 0.92*$48,330 = $44,464
  • Total Savings: $124,200

• Condensate Piping
  • No change

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Testing and Balancing
• Material: $0
• Labor: $16,560
• Total Savings: $16,560
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<table>
<thead>
<tr>
<th>Description</th>
<th>Material</th>
<th>Labor</th>
<th>Total</th>
<th>% of Total</th>
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<td>$215,880</td>
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<td>Mechanical Insulation</td>
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<td>$76,002</td>
<td>$135,000</td>
<td>5.4%</td>
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<tr>
<td>Pumps</td>
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<td>$70,686</td>
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<td>Cooling Towers</td>
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<td>VAVs</td>
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<td>$1,228</td>
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<td>0.0%</td>
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<tr>
<td>Electric Heating Coils</td>
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<td>Centrifugal Chiller</td>
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<td>$18,032</td>
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<td>AHUs</td>
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<td>Ductwork</td>
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<td>Testing and Balancing</td>
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<td>$16,560</td>
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Chilled Beam Mechanical System Cost per SF = $11.79
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<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
<th>% Decrease</th>
<th>% Increase</th>
<th>Increase</th>
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<tr>
<td>Chilled Beam</td>
<td>$215,880</td>
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<td>VAVs</td>
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<tr>
<td>Fans</td>
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<tr>
<td>Self Contained AHUs</td>
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<td>Electric Heating Coils</td>
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<td>VAV Cost</td>
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<td>Total</td>
<td>$2,479,616</td>
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</table>
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Additional Office Space w/ Chilled Beams
- Removed SCUs add office space for floors 2-7
- 360SF/floor
- 2,160SF additional office space
- Office space will lease for $12/SF/month
- Additional leasing income of $25,290/month
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Chilled Beam Schedule Impacts

- Original Schedule:
  - June 9, 2009 – February 10, 2009
  - 246 days
- Chilled Beam Schedule:
  - June 9, 2009 – March 19, 2009
  - 283 days
- Overall Project Schedule:
  - No change
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Energy Savings

- EPA estimates annual HVAC energy cost/SF for Mid-Atlantic area office building to be $1.59/SF
- Annual HVAC Cost = $1.59/SF * 210,240SF = $334,282 per year
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- Annual HVAC Cost = $1.59/SF\times210,240\text{SF} = $334,282 per year

<table>
<thead>
<tr>
<th>Energy Reduction</th>
<th>Initial HVAC Cost</th>
<th>Annual HVAC Cost</th>
<th>Annual Energy Savings</th>
</tr>
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<tbody>
<tr>
<td>20%</td>
<td>$687,704</td>
<td>$588,820</td>
<td>$98,884</td>
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<tr>
<td>30%</td>
<td>$646,497</td>
<td>$530,419</td>
<td>$116,078</td>
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<tr>
<td>40%</td>
<td>$605,290</td>
<td>$472,030</td>
<td>$133,260</td>
</tr>
</tbody>
</table>

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Payback Period

- Additional cost of $75,056 (1.03% increase)
- Savings between $66,856 and $133,713 in energy costs
- Additional $311,040/year in office leasing revenue
- Less than 1 year payback

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Conclusion

- Initial cost increase of $75,056 (1.03%)
- VAV system cost = $2,404,560 = $11.44/SF
- Chilled beam system cost = $2,479,616 = $11.79/SF
- Lower operating costs, higher revenues offset higher initial cost with less than 1 year payback
- Chilled beams increased HVAC construction duration by 37 days
- Overall project schedule not affected
- Chilled beams unfamiliar to industry professionals in United States

Recommendation

- Chilled beams should be pursued on more projects in US
- Would be appropriate to use for RTC project
Presentation Outline

• Project Overview
• Chilled Beam HVAC System (MAE) (Mechanical)
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NEC Wire Sizing

• Upsizing wire conductors has the potential to improve the energy efficiency of buildings
• Wire conductors have resistance which creates voltage drops and uses energy
• Larger conductors have lower resistance than smaller wires
• Analysis determines the feasibility of upsizing wires one size larger than NEC code minimum to reduce energy usage

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Calculations

- Circuit No. 12 on lighting panel LP-H
- Powers 2'x4' parabolic troffer luminaires
- 277V
- Connected load = 4,400 VA
- 2-#12 AWG - #12 Ground
- Luminaires are approximately 100' from panelboard
Calculations

- Current in wires = 4,400VA/277V = 15.9 amps
- The first step is to calculate the resistance of #12 wire:
  - For #12 THHN @ 75°C (From NEC Chapter 9, Table 9):
    \[ R = 2Ω/kFt \]
  - To correct resistance to 30°C, use NEC Table 8 footnote:
    \[ R_1 = 2 [1+0.00323(30-75)] = 1.71 Ω/kFt \]
  - The second step is to calculate the power loss for #12 wire:
    \[ \text{Power Loss} = I^2R = (15.9)^2 \times 1.71 \times 0.1 = 43.0 \text{ W} \]

- The third step is to calculate energy loss per year for #12 wire:
  \[ \text{Energy Loss} = 43.0 \text{ W} / 1000\text{W/kW} \times 12\text{hrs/day} \times 365\text{days/year} = 188 \text{ kWh/yr} \]
- Repeat steps for #10 wire
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#### Calculations
- **Resistance of #10 wire:**
  - For #10 THHN @ 75°C (From NEC Chapter 9, Table 9):
    \[ R = 1.20 \Omega/\text{kFt} \]
  - To correct resistance to 30°C, use NEC Table 8 footnote:
    \[ R_2 = 1.2 \times (1 + 0.00323(30-75)) = 1.03 \Omega/\text{kFt} \]
- **Power loss for #10 wire:**
  \[ \text{Power Loss} = I^2R = (15.9)^2 \times 1.03 \times 0.1 = 26.0 \text{ W} \]

- **Energy loss per year for #10 wire:**
  \[ \text{Energy Loss} = 26.0 \text{ W} / 1000 \text{W/kW} \times 12 \text{hrs/day} \times \frac{365 \text{days}}{365} = 113 \text{ kWh/yr} \]
- **Savings due to upsizing wire:**
  - initial cost increase:
    \[ \text{Cost of #12 wire and conduit} = 2.85 \text{LF} \times 100' = 285 \]
    \[ \text{Cost of #10 wire and conduit} = 3.03 \text{LF} \times 100' = 303 \]
    \[ \text{Cost difference} = 18 \]
  - Energy saved:
    \[ 188.113 = 75 \text{ kWh/yr} \]
    \[ \text{Dollar savings at $0.09 per kWh:} \]
    \[ 6.75/\text{yr} \]
    \[ \text{Dollar savings at $0.09 per kWh:} \]
    \[ 6.75/\text{yr} \]
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Discounted Payback Period

• Assume MARR = 15%

<table>
<thead>
<tr>
<th>Period</th>
<th>Cost Flow</th>
<th>Cost of Return (MARR)</th>
<th>Discounted Cash Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>($18)</td>
<td>($18)</td>
<td>($18)</td>
</tr>
<tr>
<td>1</td>
<td>$6.75</td>
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<tr>
<td>2</td>
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<td>($3.23)</td>
</tr>
<tr>
<td>3</td>
<td>$6.75</td>
<td>$10.50</td>
<td>$9.09</td>
</tr>
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</table>

$0.09/kWh – 4 year payback

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<td>($18)</td>
<td>($18)</td>
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<tr>
<td>1</td>
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<tr>
<td>3</td>
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<td>($0.18)</td>
<td>$9.09</td>
</tr>
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$0.14/kWh – 3 year payback
Other Findings

- Payback shows wire upsizing is feasible
- Most circuits do not operate at design
- Penn State Campus buildings design capacities typically 3 to 4 times average load
- Wires already upsized several times
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Possible Uses of Wire Upsizing
- Locations with constant high loads
- Data center equipment
- Large constant speed motors
- HVAC chillers

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Conclusion
- Wire upsizing feasible
- Savings not drastic
- Payback typically within a few years
- Best uses would be areas with constant high loads
- Data center equipment, large constant speed motors, HVAC chillers

Recommendation
- Apply principle only in areas of building projects with high constant loads
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Actual Construction Sequence
- February 6, 2008 – April 1, 2009; 420 days
- Constructed in 2 phases
- 46 day gap in precast member erection
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Actual Construction Sequence

- No remobilization fees were paid to the Precast Erectors, Inc. because only 1 mobilization charge was stated in contract with Clark Construction
- Precast Erectors PM estimated second mobilization costs were $70,000
- Precast Erectors absorbed second mobilization costs
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Proposed Construction Sequence

- Erect majority of building in same manner as the actual sequence except leave out south non-load bearing foundation wall instead of corner
- Erect members from inside the building
- Move crane from basement to outside foundation wall through opening in wall and erect last sequence

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Proposed Construction Sequence

- Erect majority of building in same manner as the actual sequence except leave out south non-load bearing foundation wall instead of corner
- Erect members from inside the building
- Move crane from basement to outside foundation wall through opening in wall and erect last sequence
- February 6, 2008-February 17, 2009; 377 days
- Saves 43 days in construction duration

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Cost Impacts
• GCs are reduced
• Precast Erectors would save $70,000 for the second mobilization costs
• Project cost is not affected
Conclusion

• Proposed sequence saves 43 days in construction duration
• Saves Precast Erectors $70,000 in second mobilization costs
• Does not reduce cost to owner
• Allows Clark Construction to better manage risks

Recommendation

• Use proposed sequence to reduce construction duration, minimize risks on project, allow site work to finish earlier, and save Precast Erectors second mobilization costs
• Would make project more of a success for everyone involved
Conclusion

- Chilled beams are a new HVAC technology which has the potential to drastically improve a building’s energy efficiency
- Chilled beams can be implemented at RTC BII for $75,056 with payback period less than 1 year and no schedule impact
- Wire upsizing has the potential to save energy
- Implement in areas with constant high loads
- Proposed sequence for the parking garage saves 43 days on the schedule; costs are not reduced

Recommendation

- All three analysis topics should be used for project
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Acknowledgements
- Penn State Architectural Engineering Faculty
- Clark Construction
  - Jim Martinoski
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  - Albert Flaherty
- Tindall Corporation
  - Jeff Lepard
- Friends and Family

Questions?