Hybrid Geothermal System Design & Operation for a University Campus

Commercial
Acknowledgements

• James H. Packard, PE – Director of Facilities Operations and Ted Ruth – Director of Facilities Design, Missouri University of Science & Technology, Rolla, MO. Thank you Jim and Ted, for your conviction in the success of the geothermal project, herculean efforts in obtaining project funding, and invaluable contribution during the design, construction, and start-up phases of this multi-year project.

• Jeff Urlaub, PE – President/ CEO, MEP Associates, Eau Claire, WI. Thank you Jeff for your well-engineered design of the geothermal well fields and trust in the hybrid design concept.
Project Overview

- $33 Million Project Cost
- Three (3) new hybrid geothermal plants and seven (7) existing chiller plants serve heating and cooling needs of campus
- Replaced 65-year-old coal and wood chip fired steam Power Plant
- 1,000,000 square feet of building space
- Over (21) buildings on campus CHW loop, (17) buildings on two campus HW loops
- 645 vertical bore wells, 420 to 440 feet deep
- 2-pipe CHW and HW distribution loops
Project Overview

• At each geothermal plant (Typical of 3):
  – Three (3) Heat Recovery Chillers (HRCs) with total nominal capacities of 400 tons cooling and 6,500 MBH heating
  – Any HRC can run in any operating mode: heat, cool or dual
  – Cooling towers and natural gas-fired boilers for trimming peak geothermal system loads
  – Integrated plant and campus wide controls
Project Overview

De-Coupled Primary/Secondary/Tertiary CHW Flow Schematic (Similar for Heating Water)

Configurations Applicable to MS&T Campus: #1 and #3
Project Overview

- At each existing chiller plant building (Typical of 7):
  - Modified chiller plant and associated plant building for primary/secondary pumping configuration
  - New controls for chiller plant, cooling tower and integration for campus wide operation
  - Set-point reset for chilled water and tower water based on outdoor air wet bulb temperature
Project Overview

- At each non-plant building (13 CHW & 15 HW):
  - Building CHW and HW connections modified for secondary/tertiary pumping
  - Modulating bypass flow control valves to regulate CHW and HW water flows for optimal loop delta-T’s
  - Heating coils retrofitted for 120°F heating water
Project Overview

MS&T - Geothermal Well Fields

Geo Well Fields Serving McNutt Geo Plant (Total of 210 Wells, 440 ft Deep)

Geo Well Fields Serving Straumanis-James Geo Plant (Total of 210 Wells, 440 ft Deep)

Geo Well Fields Serving Bertelsmeyer Geo Plant (Total of 225 Wells, 420 ft Deep)

Geothermal Plant Location (Typical of 3)
Project Overview

MS&T Campus - 2-Pipe Heating Water Loops (North & South)

North HW Loop

South HW Loop

1. Straumanis-James Hall
2. Emerson Electrical Engineering Hall
3. Butler-Carlton Civil Engineering Hall
4. Fulton Hall
5. Physics Building
6. MST
7. Parker Hall
8. Toomey Hall
9. Interdisciplinary Engineering Building
10. Norwood Hall
11. Schrenk Hall West
12. Centennial Hall
13. Castleman Hall
14. Schrenk Hall East
15. Rolls Building
16. James E. Bertelsmeyer Hall Geothermal Plant
17. Campus Support Facility
18. Havener Center
19. Residential College N1
20. Residential College M2 & M3
21. Home Hall
22. Engineering Management Building
23. Humanities and Social Science
24. Curtis Laws Willson Library
25. McNutt Hall
26. 1. McNutt Hall Geothermal Plant
27. Computer Science Building
28. Engineering Research Lab
Project Overview

MS&T Campus - 2-Pipe Chilled Water Loop

1. Straumanis-James Hall
2. Straumanis-James Hall Geothermal Plant
3. Emerson Electrical Engineering Hall
4. Butler-Carlton Civil Engineering Hall
5. Fulton Hall
6. Physics Building
7. MSTR
8. Toomey Hall
9. Interdisciplinary Engineering Building
10. Norwood Hall
11. Schrenk Hall West
12. Centennial Hall
13. Castelman Hall
14. Schrenk Hall East
15. Rolla Building
16. James E. Bertelsmeyer Hall / Geothermal Plant
17. Campus Support Facility
18. Havener Center
19. Residential Collage #1
20. Residential Collage #2 & #3
21. Morris Hall
22. Engineering Management Building
23. Humanities and Social Science
24. Curtiss Laws Willson Library
25. McNutt Hall
26. McNutt Hall Geothermal Plant
27. Computer Science Building
Project Timeline

• 2010 – Campus Wide Energy Study

• 2011 – Campus Wide Design Work

• 2012 – Design Work, Well Fields Drilling (May through Dec)

• 2013 – Construction (Plants/ Piping Loops/ Building Modifications)

• 2014 – Construction, Commissioning, Partially Automated Geo Plants for Cooling & Heating; Power Plant Boilers De-Commissioned on May 21st

• 2015 – Campus Wide Fully Automated Operation since Feb 1st; Commissioning Substantially Completed March 31st
Hybrid Design

• Utilized custom-built hourly energy model of campus and life cycle cost analysis to optimize bore-wells count

• Developed a comprehensive design and integration strategy for accomplishing the project

• Expanded on in-house expertise with consultants as needed
Hybrid Design

• Existing (7) campus electric chiller plants supplement the HRCs cooling capacity and provide 65% redundancy

• HRCs projected to handle 75% of campus cooling energy (ton-hours) annually

• New gas-fired boilers to supplement HRCs heating capacity and provide 100% redundancy

• Number of bore-wells optimized to handle 90% of campus heating energy (kBTUs) annually
% of Total Campus Heating Load Handled by Geothermal HRCs (TMY Model Prediction vs Actual Metered Data for Years 1 and 2)

- TMY Weather Model - Projected Monthly Heating Load Handled by Geothermal HRCs as % of Total Campus Heating Load
- Year 1 - Monthly Heating Load Handled by Geothermal HRCs as % of Total Campus Heating Load (March 2015 thru February 2016)
- Year 2 - Monthly Heating Load Handled by Geothermal HRCs as % of Total Campus Heating Load (March 2016 thru February 2017)
Hybrid Design

% of Total Campus Cooling LoadHandled by Geothermal HRCs
(TMY Model Prediction vs Actual Metered Data for Years 1 & 2)

TMY Weather Model - Projected Monthly Cooling Load Handled by Geothermal HRCs as % of Total Campus Cooling Load

Year 1 - Monthly Cooling Load Handled by Geothermal HRCs as % of Total Campus Cooling Load (March 2015 thru February 2016)

Year 2 - Monthly Cooling Load Handled by Geothermal HRCs as % of Total Campus Cooling Load (March 2016 thru February 2017)
Hybrid Design

MS&T Plants - Heating Water Loads Summary @ OAT of 9 deg F
# Hybrid Design

## Table: Hybrid Design Parameters

<table>
<thead>
<tr>
<th></th>
<th>100%</th>
<th>100%</th>
<th>97%</th>
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<tbody>
<tr>
<td>Online HRCs Heating Load as % of Usable Capacity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Online Boilers Heating Load as % of Rated Capacity</td>
<td>54%</td>
<td>58%</td>
<td>0%</td>
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</tbody>
</table>

- Heating Plant Available for Automatic Sequencing: Yes
Hybrid Design

MS&T Plants - HW Loop Pumps & Building Valves @ OAT of 9 F

<table>
<thead>
<tr>
<th>Non-Pont Buildings on Mcclure Stairtions Marine North HW Loop</th>
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<tbody>
<tr>
<td>HW Bypass Valve Comand % Open</td>
<td>79.3% open</td>
</tr>
<tr>
<td>HW Bypass Valve % Open Set Point</td>
<td>70.0% open</td>
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<tr>
<td>HW Bypass Valve % Open Error</td>
<td>-2.0% open</td>
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<tr>
<td>HW Bypass Valve % Open Corrected</td>
<td>-2.0% open</td>
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<td>HW Bypass Valve % Corrected</td>
<td>-2.0% open</td>
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<thead>
<tr>
<th>Non-Pont Buildings on Bertiehoneyer Plant South HW Loop</th>
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<tbody>
<tr>
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<td>79.0% open</td>
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<tr>
<td>HW Bypass Valve % Open Set Point</td>
<td>70.0% open</td>
</tr>
<tr>
<td>HW Bypass Valve % Corrected</td>
<td>-2.0% open</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Geothermal Heating Plant</th>
<th></th>
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<tbody>
<tr>
<td>HW Bypass Valve Comand % Open</td>
<td>100.0% open</td>
</tr>
<tr>
<td>HW Bypass Valve % Open Set Point (user Adjustable)</td>
<td>70.0% open</td>
</tr>
<tr>
<td>HW Loop Pump Run Status</td>
<td>On</td>
</tr>
<tr>
<td>HW Bypass Valve % Open Error</td>
<td>-100.0%</td>
</tr>
</tbody>
</table>

All HW Loop Pumps Running Well Below Full Speed & All Buildings are Satisfied!!!
## Hybrid Design

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<tr>
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<th>53.0% Cmd</th>
<th>100.0% Cmd</th>
<th>NA</th>
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<tbody>
<tr>
<td>53.0% Cmd</td>
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<td>56.0% Cmd</td>
<td>36.6% Cmd</td>
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Hybrid Design

MS&T Plants - Chilled Water Loads Summary @ OAT of 10 F

Useful Evaporator Water Production at HRCs in Heat Mode (< 50 deg F)
Hybrid Design

<table>
<thead>
<tr>
<th>198 tons</th>
<th>283 tons</th>
<th>92 tons</th>
</tr>
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</table>

[Diagram of a hybrid design with weight distribution]
Hybrid Design

MS&T Bertelsmeyer (BERT) Plant - Geothermal Water Flow & Temperatures @ OAT of 9 deg F
Hybrid Design

Lowest Return Temperature to Wells = 48 deg F
Hybrid Design

MS&T Bertelsmeyer Plant - Condenser Water Flow & Temps @ OAT of 9 F

All HRCs are Fully Loaded!!!
Hybrid Design
Hybrid Design

MS&T Bertelsmeyer Plant - Heating Water Flow & Temps @ OAT of 9 F

Boiler HW Flow Controlled such that HW Bypass Equals Set-Point!!!

Only (1) Boiler is Online and is Partly Loaded!!!
Hybrid Design

Boiler HW Flow Controlled such that HW Bypass Equals Set-Point!!!
Hybrid Design

MS&T Plants - Chilled Water Loads Summary @ OAT of 97 F

**Chiller Out Of Service!!!**
Hybrid Design

<p>| | |</p>
<table>
<thead>
<tr>
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<tr>
<td>CAMPUS Width</td>
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<tr>
<td>3,264 tons</td>
<td></td>
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<tr>
<td>339 tons</td>
<td></td>
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<tr>
<td>7</td>
<td></td>
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<tr>
<td>2</td>
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<td>6</td>
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<tr>
<td>3,771 tons</td>
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<td>3,593 tons</td>
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<td>2,689 gpm</td>
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<td>-952 gpm</td>
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<tr>
<td>-1,754 gpm</td>
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<tr>
<td>87 %</td>
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<tr>
<td>91 %</td>
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</tbody>
</table>
Hybrid Design

MS&T Plants - Heating Water Loads Summary @ OAT of 97 F

(1) HRC in Dual Mode for South HW Loop and (1) HRC in Dual Mode for North HW Loop!!!
<table>
<thead>
<tr>
<th># of Online HRCs in Dual Mode</th>
<th>1</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Online Gas-Fired Boilers</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Hybrid Design

MS&T Plants - CHW Loop Pumps & Building Valves @ OAT of 97 F

All Online Loop Pumps Running Well Below Full Speed and Meeting Bldg CHW Demand!!
Hybrid Design

<table>
<thead>
<tr>
<th>CHW Bypass Valve Open Command</th>
<th>26.6% open</th>
<th>48.8% open</th>
<th>34.3% open</th>
<th>42.3% open</th>
<th>34.1% open</th>
<th>31.9% open</th>
<th>31.1% open</th>
<th>21.4% open</th>
<th>35.5% open</th>
<th>37.8% open</th>
<th>29.1% open</th>
<th>32.0% open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant CHW Loop Pump Cmd</td>
<td>19.0%</td>
<td>22.2%</td>
<td>29.2%</td>
<td>22.9%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>29.2%</td>
<td>29.2%</td>
<td>29.2%</td>
<td>29.2%</td>
<td>0.0%</td>
<td></td>
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</tbody>
</table>
Hybrid Design

MS&T Plants & Bldgs - Loop Side Chilled Water Temps @ OAT of 97 F

| Plant Buildings on CHW Loop | ERL | Ft. Ticonderoga | E. Physics | Centennial | Schemek East | Rolla | RMB Life | RMB Life 253 | Eng Man | Human Library | Wilson Library | MRBC Steam
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Loop Side CHW Supply Temp (F)</td>
<td>43.7 deg F</td>
<td>43.7 deg F</td>
<td>44.8 deg F</td>
<td>44.4 deg F</td>
<td>43.5 deg F</td>
<td>43.8 deg F</td>
<td>44.3 deg F</td>
<td>44.5 deg F</td>
<td>44.1 deg F</td>
<td>44.5 deg F</td>
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</tr>
<tr>
<td>Loop Side CHW Return Temp (F)</td>
<td>56.9 deg F</td>
<td>56.9 deg F</td>
<td>55.8 deg F</td>
<td>55.8 deg F</td>
<td>54.8 deg F</td>
<td>54.2 deg F</td>
<td>54.0 deg F</td>
<td>54.0 deg F</td>
<td>52.6 deg F</td>
<td>60.4 deg F</td>
<td>62.0 deg F</td>
<td>56.1 deg F</td>
</tr>
<tr>
<td>Loop Side CHW Delta-T (F)</td>
<td>12.6 deg F</td>
<td>12.4 deg F</td>
<td>14.3 deg F</td>
<td>11.5 deg F</td>
<td>21.3 deg F</td>
<td>10.7 deg F</td>
<td>11.8 deg F</td>
<td>5.7 deg F</td>
<td>3.0 deg F</td>
<td>14.0 deg F</td>
<td>17.8 deg F</td>
<td>12.2 deg F</td>
</tr>
<tr>
<td>Bldg Side CHW Supply Temp (F)</td>
<td>45.5 deg F</td>
<td>45.7 deg F</td>
<td>45.7 deg F</td>
<td>49.3 deg F</td>
<td>48.6 deg F</td>
<td>47.6 deg F</td>
<td>45.9 deg F</td>
<td>46.0 deg F</td>
<td>46.0 deg F</td>
<td>46.0 deg F</td>
<td>46.0 deg F</td>
<td>40.8 deg F</td>
</tr>
<tr>
<td>Bldg Side CHW Return Temp (F)</td>
<td>57.1 deg F</td>
<td>59.5 deg F</td>
<td>59.6 deg F</td>
<td>55.1 deg F</td>
<td>54.2 deg F</td>
<td>54.5 deg F</td>
<td>57.5 deg F</td>
<td>45.4 deg F</td>
<td>53.0 deg F</td>
<td>61.3 deg F</td>
<td>62.2 deg F</td>
<td>56.4 deg F</td>
</tr>
<tr>
<td>Bldg Side CHW Delta-T (F)</td>
<td>11.3 deg F</td>
<td>11.6 deg F</td>
<td>12.9 deg F</td>
<td>6.3 deg F</td>
<td>17.6 deg F</td>
<td>8.9 deg F</td>
<td>11.9 deg F</td>
<td>12.4 deg F</td>
<td>15.0 deg F</td>
<td>15.7 deg F</td>
<td>17.4 deg F</td>
<td>9.8 deg F</td>
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<table>
<thead>
<tr>
<th>Plant Buildings on CHW Loop</th>
<th>Foote Library</th>
<th>Stearns-James</th>
<th>McNutt</th>
<th>Havens</th>
<th>Butter-Collins</th>
<th>Toomey</th>
<th>Schwenk West</th>
<th>Comp Sci</th>
<th>Emerson</th>
<th>Ceilometer</th>
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<tbody>
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<td>Plant Side CHW Supply Temp (F)</td>
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<td>44.7 deg F</td>
<td>44.1 deg F</td>
<td>49.3 deg F</td>
<td>64.2 deg F</td>
<td>44.4 deg F</td>
<td>44.3 deg F</td>
<td>44.8 deg F</td>
<td>44.0 deg F</td>
</tr>
<tr>
<td>Plant Side CHW Return Temp (F)</td>
<td>52.6 deg F</td>
<td>55.0 deg F</td>
<td>58.8 deg F</td>
<td>51.9 deg F</td>
<td>54.1 deg F</td>
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<td>61.1 deg F</td>
<td>48.8 deg F</td>
<td>48.2 deg F</td>
<td>53.3 deg F</td>
</tr>
<tr>
<td>Plant Side CHW Delta-T (F)</td>
<td>6.9 deg F</td>
<td>11.2 deg F</td>
<td>14.1 deg F</td>
<td>5.6 deg F</td>
<td>0.0 deg F</td>
<td>8.4 deg F</td>
<td>9.9 deg F</td>
<td>3.6 deg F</td>
<td>3.5 deg F</td>
<td>0.6 deg F</td>
</tr>
<tr>
<td>Loop Side CHW Supply Temp (F)</td>
<td>43.0 deg F</td>
<td>44.1 deg F</td>
<td>44.2 deg F</td>
<td>45.8 deg F</td>
<td>46.3 deg F</td>
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<tr>
<td>Loop Side CHW Return Temp (F)</td>
<td>55.4 deg F</td>
<td>55.6 deg F</td>
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<td>53.9 deg F</td>
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<td>56.0 deg F</td>
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<td>53.7 deg F</td>
<td>53.3 deg F</td>
</tr>
<tr>
<td>Loop Side CHW Delta-T (F)</td>
<td>12.6 deg F</td>
<td>12.5 deg F</td>
<td>16.3 deg F</td>
<td>13.7 deg F</td>
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<td>12.3 deg F</td>
<td>9.6 deg F</td>
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</tbody>
</table>

Links: CHW Plants, CHW Pumps, CHW Alarms, CHW CGS, CHW Laredo
Outdoor Air: Dry Bulb Temp, 96.7 deg F, 44.8% Relative Humidity, Wet Bulb Temp, 78.3 deg F
Monday, July 13, 2015, 03:59 PM
## Hybrid Design

<table>
<thead>
<tr>
<th>Loop Side CHW Supply Temp (F)</th>
<th>44.7 deg F</th>
<th>43.7 deg F</th>
<th>44.8 deg F</th>
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<th>43.2 deg F</th>
<th>43.0 deg F</th>
<th>45.7 deg F</th>
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<td>12.9 deg F</td>
<td>12.0 deg F</td>
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<td>11.5 deg F</td>
<td>21.3 deg F</td>
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<td>11.8 deg F</td>
<td>7.0 deg F</td>
<td>8.0 deg F</td>
<td>14.0 deg F</td>
<td>17.9 deg F</td>
<td>12.2 deg F</td>
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| Loop Side CHW Supply Temp (F) | 43.6 deg F | 44.1 deg F | 44.2 deg F | 45.8 deg F | 45.3 deg F | 45.2 deg F | 44.2 deg F | 45.0 deg F | 45.1 deg F | 45.3 deg F |
| Loop Side CHW Delta-T (F)     | 12.8 deg F | 12.5 deg F | 15.3 deg F | 13.7 deg F | 8.6 deg F  | 14.3 deg F | 11.8 deg F | 12.3 deg F | 8.8 deg F  | 8.0 deg F  |
Hybrid Design

M&ST Bertelsmeyer Plant - Tower Water Flow & Temps @ OAT of 89 F

Geothermal Water Temp Returning to Well Fields Controlled to 90 deg F!!!
Hybrid Design

MS&T Engg Res Lab Bldg (Non-Plant) CHW Flow & Temp @ OAT of 48 F

Engineering Research Lab Chilled Water Loop

Loop Side CHW Delta-T => Bldg Side CHW Delta-T for Optimal Control

Bypass Flow % Controlled to Set-Point %
Hybrid Design

MS&T Engg Res Lab Bldg (Non-Plant) HW Flow & Temp @ OAT of 49 F

Loop Side HW Delta >= Bldg Side HW Delta-T for Optimal Flow Control

HW Bypass Flow % Controlled to Bypass Flow Set-Point %
Operation and Maintenance

• Eliminated deferred maintenance of 65-year-old coal and wood chip fired steam plant

• Replaced 40-year-old single pipe chilled water loop with two-pipe chilled water system sized to accommodate future expansion of campus and improved space comfort

• Enabled campus facilities department to focus on maintenance items by having the automation system optimally take care of the campus cooling and heating equipment operation: 24 hours a day, 365 days a year
Operation and Maintenance

- Automated Systems Control Graphics with hyperlinks for faster Access
- Critical Equipment Fail to Run Alarm Notification & Automatic Switch Over
- Critical Out of Service Equipment Summary & Operator Interface
- Out of Control Temperature & Other Equipment Alarm Notifications
Energy & Cost Savings

- Designed to reduce total energy use of Education and General campus buildings by 50% (First year reduction @ 57%)

- Projected to save $1.1 Million per year in operational costs for a 30 year simple payback

- Estimated 90% of annual heating energy and 75% of annual cooling energy from geothermal resources (First year @ 97% and 82% respectively)
Environmental Impact

• Anticipated to reduce carbon footprint by 25,000 tons of CO2/year (First year reduction @ 25,013 tons)

• Projected to save 10 million gallons/year of water by eliminating makeup water at steam boilers and reducing makeup water at cooling towers (First year reduction @ 18.7 million gallons – suspect leak in old piping that was fixed when the old pipe was replaced with new piping)
Our Partners from the Geothermal Industry

- MEP Associates
- Durbin Enterprises
- Ground Source Systems – Geo-Enterprises, Inc.
Questions?

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