Eye-opening GSHP System Performance: *Reality* versus *Design* for the life of a Project

Session C: Technical
Learning Objectives

• Our industry needs real performance feedback to grow: How do we get it?
• Design Phase In-situ testing versus “Effective” GHX properties, do we see a difference?
• What about the building loads changing?
• When there is a difference from design to reality, what can be done to optimize system performance?
• How do we close the performance feedback loop?
Acknowledgements

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• Bob Braam – Greensleeves LLC
1. Design, construct, operate and optimize; What can happen to make things different?

2. Case Studies
   A. Overheated Florida High School
   B. Hot/cold borefields in North Carolina VA Facilities
   C. The Michigan high school that “grew too much”
   D. The Michigan high school that is saving the Owner big $$$ in construction
   E. An Iowa jail that’s the “hot” place to be
   F. I like cows, you should too

3. Conclusions & A Challenge
Design Process

Energy modeling

In-situ Formation Testing

Iterative process of GHX simulations
Design Process

How will you ever find out?
Construction Process

How will you ever find out?
The construction is finally done…

How will *you* ever find out?
Probably not until the phone rings...
There is a better way, but first...
Projects with some challenges...

...and how they got fixed.

But first, an explanation.
Site-based Energy Heat Pump Systems

Many configuration options!
Reactive v. Predictive Control

Reactive (Real-time) or “ASHRAE Hybrid” Mode:

- When GHX leaving water temperatures exceed a setpoint, the CCCT is enabled
- Typically this is when:
  - Outside air temperature is hottest
  - Outside air humidity is highest
  - Electricity is the most expensive
- Typically uses MORE ENERGY than fullsize GHX

Predictive (Pre-Conditioning) Mode:

- Intelligent controls “look” to a future horizon and predict GHX LWT’s
- Intelligently decide when to operate the CCCT:
  - Cooler and dryer weather
  - Less expensive energy
  - Less water usage
- Self-adapting algorithms adjust automatically

Can use LESS ENERGY than fullsize GHX!
Time shifting Heat Rejection?

Run Hours

Wet Bulb Temp °F

Cooling Tower Run Hours VS. Wet Bulb Temperature
- Geothermal
- AHRME Hybrid
- Wet Bulb °F
Or explained in another way...

• Running a CCCT creates an “artificial” heating load
  o Especially when run in the winter months during cool weather – makes Physics work for us!
• In reality we are simply balancing the annual cooling and heating loads
  o We know that balanced borefields work better!
• We are also resetting any potential temperature creep from year to year
Reactive v. Predictive Conclusion…

Reactive (Real-time) or “ASHRAE Hybrid” Mode:

Predictive (Pre-Conditioning) Mode:

GHX + ASHRAE Hybrid CCCT = “The Dark Side”

©Back to the Future

Endorsed by Dr. Emmet Brown!

©Star Wars

Not really…
Overheated Florida High School

- Built in 2000
- Nominal 1,000 ton peak cooling load
- Issues with borefield installation – varying depths and 32 coiled loops
- Installed approximately 179 borefeet per peak ton of cooling
- Temperatures started to creep reaching well over 100°F range
- Compressor failures started in 2006 – note these are non-extended range GSHP’s
- 2014 – diagnostic software was installed to track the loads and the GHX response
Overheated Florida High School

Actual loads v. Design Loads
Seven (7) year simulation results; adding a nominal 375 ton cooling tower:

<table>
<thead>
<tr>
<th></th>
<th>Existing GHX</th>
<th>Real-time Mode</th>
<th>Pre-conditioning Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min GHX Temperature</td>
<td>70°F</td>
<td>68°F</td>
<td>63°F</td>
</tr>
<tr>
<td>Max GHX Temperature</td>
<td>104°F</td>
<td>96°F</td>
<td>90°F</td>
</tr>
<tr>
<td>Avg GHX Temperature</td>
<td>82°F</td>
<td>78°F</td>
<td>68°F</td>
</tr>
<tr>
<td>Hours &gt; 90°F</td>
<td>978</td>
<td>238 (-76%)</td>
<td>0 (-100%)</td>
</tr>
<tr>
<td>Compressor Energy Reduction</td>
<td>Base Case</td>
<td>-9%</td>
<td>-45%</td>
</tr>
<tr>
<td>$ Returned per $ CCCT</td>
<td>NA</td>
<td>$1.27</td>
<td>$7.95</td>
</tr>
</tbody>
</table>

Every dollar spent on the CCCT returns nearly $8!!!
**North Carolina VA Housing**

- Two (2) housing units – one mountain, one valley
- Single pipe heat pump configuration
- Six separate borefields (GHX’s) per building
- Problems with overheating GHX as well as overcooling (no antifreeze)
North Carolina VA Housing

Peak Net Cooling Load: Design 107 Tons
Actual 126 Tons = 18% Increase in Peak

<table>
<thead>
<tr>
<th>Total Ton-Hours</th>
<th>Cooling Design: 12,979</th>
<th>Cooling Actual: 31,342</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ton-Hours</td>
<td>Heating Design: 12,963</td>
<td>Heating Actual: 3,996</td>
</tr>
<tr>
<td></td>
<td>141% Increase</td>
<td>69% Decrease</td>
</tr>
</tbody>
</table>

Whole Building Actual vs. Design

- Actual
- Design
- Trend (Actual)
- Trend (Design)
North Carolina VA Housing

“Effective” GHX Thermal Conductivity

Red = Actual
Blue = Predicted
When both heating and cooling occur, we can do a long-term in-situ test on the “effective” GHX Thermal Conductivity.
When both heating and cooling occur, we can do a long-term in-situ test on the “effective” GHX Thermal Conductivity.
North Carolina VA Housing

Results:

• Significant variance in GHX effective performance versus design

• Some variance of actual HVAC loads to design – some due to temperature setpoint changes
  
  o Residents prefer warmer temperatures all year – added heating load, diminished cooling load

• Single pipe design exacerbated the impact of “out of range” entering water temperatures causing frequent GSHP trips

• But most interesting is that the load diversity was great enough such that if all six (6) GHX’s (each building) were combined, the EWT’s could stay within the needed range

  Currently they are combining the GHX’s
Growing High School

- Built in 2001, Natatorium added in 2005
- Several major additions to the GHSP System, but not GHX
- Summer GSHP EWT climbs to 120°F+
- Numerous nuisance trips and unhappy occupants
- Applied load monitoring software to sort it out...
Growing High School

Observations:

• Major irrigation system for athletic fields
• Runs nightly in summer for 6 to 8 hours
• City water temperatures in the 60’s°F range
• Irrigation pipe passes through GHX mechanical room
• Serendipity!
• Let’s use the irrigation as a closed-circuit cooling tower!
Growing High School

- Isolated the GHX flow from the building
- Added the irrigation HX
- Irrigation heat rejection can hit 100+ tons!
- Load monitoring software also used to identify GHX capacity – could it support 1 MMBTU snow melt? Yes!
Growing High School
Growing High School

Note when irrigation turned off!

125°F!!!

80°F!!!
The “BIG” Borefield

• Built in 2003

• Original design of GHX: 48°F Min to 85°F Max

• Actual operation: 55°F to 75°F, extra capacity available!

• Load monitoring software installed

• New school building proposed to be constructed adjacent
  with $900,000 GHX...

• But by knowing the available capacity and having the proper
  controls, the School District can tie the new building into the
  old GHX and redirect construction dollars!
One “Hot” County Jail

• Built in 2009

• 58 ton peak load

• 9.9:1 cooling dominant

• GHX leaving water temperatures crept to 115°F
One “Hot” County Jail

**Option #1: Real-time CCCT Approach**

- Apply 38 ton CCCT
- Operate real-time in “ASHRAE Hybrid” mode
One “Hot” County Jail

Option #2: Predictive CCCT Approach – look to the future!

- Apply 38 ton CCCT
- Operate in pre-conditioning mode
One “Hot” County Jail

Real-time

Predictive

Lower EWT = Lower Cooling Energy!
Simulation results; adding a nominal 38 ton cooling tower:

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<td>63°F</td>
</tr>
<tr>
<td>Max GHX Temperature</td>
<td>115+°F</td>
<td>96°F</td>
<td>90°F</td>
</tr>
<tr>
<td>Load Adjusted GHX Temperature</td>
<td>Not sure yet!</td>
<td>81°F</td>
<td>73°F 8°F cooler!</td>
</tr>
<tr>
<td>CCCT kWh</td>
<td>NA</td>
<td>13,751</td>
<td>11,343 17.5% less</td>
</tr>
<tr>
<td>CCCT Water kGal</td>
<td>NA</td>
<td>159</td>
<td>81 49% less</td>
</tr>
</tbody>
</table>
One “Hot” County Jail

Dropping from 81°F to 73°F Load-adjusted EWT:

Approx. 11% less
Dairy Application???

- 2500 dairy cattle
- Each cow produces 75 pounds of milk per day
- Must be chilled from 98°F to 38°F
  - This is about 10,500 BTU’s per cow
- Milking goes on 24/7 – no off time
- Also need around 5.5 gallons of hot water per cow per day for cleaning and flushing
- This is California – major water issues

Does “time shifting” heat rejection make sense???
Dairy Application

System Concept:

• Heat Recovery Central Heat Pump (nominal 40 tons)
• Make chilled fluid for chilling milk
• Make hot water for cleaning purposes
• Small vertical closed loop GHX (1.4 borefeet per cow)
• Small closed-circuit cooling tower (15 or 36 tons)
Did it “work”????

Versus conventional water-cooled refrigeration, no heat recovery and no GHX:

- Reduction in water usage per year:
  - 15 ton CCCT: 79% less!!!
  - 36 ton CCCT: 87% less!!!

- Energy cost reduction?
  - Natural gas (cheap) is tough, maybe 2-3% less or roughly equal.
  - Propane is no brainer, like 25% less!

**Bottom line:** Time shifting heat rejection can make sense in MANY applications!
1. We can’t fix what we can’t measure, nor can we optimize it.

2. Consider including performance tracking analytics on EVERY PROJECT (new or old):

   A. Measure real building loads (GHX flowrate) and compare to design and/or historical loads

   B. Measure real GHX response (GHX entering/leaving temperatures and outside air temperature)
Conclusions

3. Forecast when things are going south, BEFORE the issue hits!

4. Know how to address a change in loads...for real, not just guessing

5. Know what is the available capacity for future additions
A Challenge

Let’s have projects that better and smarter over time!

Then we will too!
Coming in November: Free Online GSHP Scoping Tool!

• 16 standard commercial building types (NREL)
• 16 ASHRAE Climate Zones
• Conventional HVAC v. GSHP Fullsize GHX & Preconditioned GHX – First Cost and Energy Cost
Questions?

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