ASHRAE Headquarters
GSHP vs. VRF

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Project Team

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A living laboratory

- Over 1000 measurement points
- 2-story office building, built in 1965
- Renovated and enlarged in 2007-2008
- Open plan office design allows for more daylighting
- Three systems:
  - Variable refrigerant flow system serving 1\textsuperscript{st} floor
  - Ground source heat pump system serving 2\textsuperscript{nd} floor
  - Dedicated outdoor air system serving both floors
First floor / VRF System

- 17,213 ft² (1599 m²) served by VRF system
- Not served by metered VRF system:
  - Computer server room
  - Rear staircase
  - Entry foyer
- Served:
  - Office space
  - Mailroom
  - Learning Center
- Two outdoor heat-recovery units (28 tons nominal capacity)
- 22 indoor FCU
VRF Controls

• Single setpoint.
• Users can reset thermostats ±3°F
• System attempts to maintain setpoint, within ±1°F
• Individual units do not switch back and forth between heating and cooling, though.
• Adjacent units in open floor plan office do run in opposite modes.
Second Floor / GSHP System

• GSHP serves entire 2\textsuperscript{nd} floor + rear stairwell.
• Total floor area 15,558 ft\textsuperscript{2}. (1445 m\textsuperscript{2})
• Office space and two conference rooms.
GSHP System

- 12 boreholes, 400 ft. deep
- 14 water-to-air heat pumps, 31.5 tons nominal capacity
- Heat pumps:
  - Two-stage
  - ECM fan motors, variable speed
- Staged controls:
  - Separate heating/cooling setpoints 68°F/74°F typical
  - Temperature deviates > 1.5°F: low-stage
  - Temperature deviates > 2.5°F: high-stage
  - Users can reset thermostats ±3°F
DOAS

- Provides partly conditioned ODA to both floors.
- Generally, always lower than room temperature.
- Sometimes overcools.
- Increases heating loads, decreases cooling loads.
Qualitative comparison of loads

• 1\textsuperscript{st} floor and 2\textsuperscript{nd} floor: same lighting and plug load densities.

• Occupancy:
  • 1\textsuperscript{st} floor (normal): 400 ft\textsuperscript{2}/person
  • 2\textsuperscript{nd} floor (normal): 259 ft\textsuperscript{2}/person
  • 1\textsuperscript{st} floor, learning center: used \textasciitilde26 hours/month

• DOAS average flow rate:
  • 1\textsuperscript{st} floor: 2560 CFM
  • 2\textsuperscript{nd} floor: 1480 CFM
Qualitative comparison of loads

• Rooms on 2\textsuperscript{nd} floor have heat gains from roof.
• 1\textsuperscript{st} floor has more glass façade, but part of this is conditioned by non-metered VRF systems.
• As a result:
  • 1\textsuperscript{st} floor has higher heating loads.
  • 2\textsuperscript{nd} floor has higher cooling loads.
  • Cooling loads are much higher than heating loads.
Results

• Energy consumption
• Heating and Cooling Loads
• System COP and EER
• Why?
Total Monthly Energy Use

[Graph showing monthly energy use for GSHP, VRF, and DOAS from Jul-11 to May-13.]
Monthly Energy Use per ft$^2$
Avg. Power vs. Outdoor Temperature

Ambient Dry Bulb Temperature, °F

Average Power Use, W/ft²

GSHP
VRF
DOAS
VRF Heating and Cooling

![Graph showing VRF Power Use vs. Ambient Dry Bulb Temperature]

- **Average VRF Power Use, W/ft²**
- **Ambient Dry Bulb Temperature, °F**

- **Red** bars represent Heating
- **Blue** bars represent Cooling
GSHP Heating and Cooling
Avg. Power – Cooling Only

![Graph showing average power use vs ambient dry bulb temperature for GSHP and VRF systems. The graph displays a trend where power use increases with higher ambient temperatures.](image-url)
Avg. Power – Heating Only
A moderate day
April 3, 2013
Morning low: 43°F
Afternoon high: 63°F
Power Use

![Graph showing Power Use with VRF and GSHP lines](image-url)
GSHP Zone Temperatures
VRF Zone Temperatures (Cooling)

Adjacent zone was heating
VRF Zone Temperatures (Heating)
Why is GSHP so much better?

- Source temperatures.
- Equipment efficiency at actual source temperatures.
- Apparent control issue – most VRF units run most of the time under moderate load conditions.
- Unnecessary (?) simultaneous heating and cooling.

- Loads are different. (Yes, but how much?)
Source Temperatures

![Graph showing temperature data over time for Ambient air and Ground Loop Water Supply.]
Heating and cooling provided

- How much heating and cooling are provided by each system?
- Heat pumps and 14 VRF FCUs:
  - Need air flow rate + temperatures and (for cooling) humidities.
Actual Available Measurements

• Airflow – from flow hood measurements (VRF system changed control boards and flows in April 2012)
• Discharge air temperature
• Zone air temperature
• Zone air humidity
Estimated quantities

• Entering and discharge air humidities
  • GSHP system, from measurements in one zone
  • VRF system, from mfr. data, SHF=f(EAT, ODAT); spot-checked by us
Uncertainty Analysis

• Details in 2nd ASHRAE Journal paper.

• Accounts for:
  • Sensor errors
  • Approximations like using the zone humidity to estimate entering air humidity
  • Aggregation (reduces uncertainty)

• Final uncertainties for entire systems.

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<thead>
<tr>
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<th>GSHP</th>
<th>VRF</th>
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<tbody>
<tr>
<td>Cooling</td>
<td>+14/-11%</td>
<td>±5%</td>
</tr>
<tr>
<td>Heating</td>
<td>±7%</td>
<td>±4%</td>
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</table>
Monthly Heating Provided

Heating Provided, kWh/ft²

- GSHP
- VRF

Graph showing monthly heating provided for GSHP and VRF systems from July 2011 to May 2013.
Heating and Cooling Provided

• For July 2011 – March 2012:
  • GSHP provides 62% less heating than VRF
  • GSHP provides 6% more cooling than VRF

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<tr>
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<th>GSHP System</th>
<th>VRF System</th>
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<tbody>
<tr>
<td>Cooling Provided</td>
<td>12.1</td>
<td>11.4</td>
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<tr>
<td>(MBTU/sq. ft.)</td>
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<tr>
<td>Heating Provided</td>
<td>2.3</td>
<td>6.0</td>
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<tr>
<td>(MBTU/sq. ft.)</td>
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Monthly System Heating COP

Heating System COP

GSHP  VRF

[Bar chart showing Heating System COP for GSHP and VRF over months from Jul-11 to May-13. The graph includes error bars for each month, indicating variability in COP values.]
Monthly System Cooling EER

The chart shows the monthly system cooling EER for GSHP and VRF systems from July 2011 to May 2013. The EER values are plotted for each month, and the error bars indicate the variability in the data. The GSHP systems generally have higher EER values than the VRF systems for most months.
Cooling performance
Heating Performance

![Graph showing Heating Performance](image-url)
Counterintuitive trends

• GSHP system heating COP goes up from 1\(^{st}\) winter to 2\(^{nd}\) winter.
• For both systems, system cooling EER increases with increasing ODA temperature (to a point)
• For GSHP system, performance increases with higher loads. (next slide)
Why is GSHP EER better in hot months?
Why does GSHP heating COP improve from 1\textsuperscript{st} year to 2\textsuperscript{nd} year?

![Graph showing Heating System COP for GSHP and VRF over different months from July 2011 to May 2013. The COP values increase over time, with GSHP generally showing higher COP compared to VRF.]
Why does GSHP heating COP improve from 1\textsuperscript{st} year to 2\textsuperscript{nd} year?

- Pump control: differential setpoint on loop reduced from 20 psig to 8 psig
Why are trends counterintuitive?

• For GSHP:
  • Entering fluid temperature does not correspond directly to outdoor air temperature.
  • Higher run time fractions correspond to less pumping energy and parasitic losses (per unit cooling or heating provided)

• For VRF (we speculate):
  • Simultaneous heating and cooling may not be as efficient as imagined.
Conclusions

- GSHP system significantly outperforms VRF system.
- For July 2011-March 2012:

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<th>VRF</th>
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<tbody>
<tr>
<td>Heating System COP</td>
<td>3.3 ±0.2</td>
<td>2.0 ±0.1</td>
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<tr>
<td>Cooling System EER</td>
<td>14.5 ±2.0</td>
<td>8.5 ±0.4</td>
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</table>
Conclusions (Why?)

- GSHP has more favorable source temperatures.
- Heat pump unit efficiency is higher than VRF efficiency over actual range of operation.
- VRF controls lead to unnecessary (?) heating and cooling.
Thanks!

- GEO
- Southern Company
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