DEVELOPMENT AND VALIDATION OF NUMERICAL MODELS OF BHE FOR GSHP

Double U-tube type and Concentric tube type

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Outline of study

Simulation tools for evaluation and design of GSHP

- EED (Sanner et al.)
- GLHEPRO (Spiter, 2000)
- COSUND / NUSOND (Eugster, 1991)
- TRADIKON-3D (Sanner et al., 1996)
- HST2D / 3D
- SBM (Eskilson, 1987)
- TRNSYS with DST-module (Pahud & Hellstrom, 1996)

In order to improve the precision, evaluate quantitatively

We need transient analysis model
Outline of GSHP system installed in a residence

**Residence description**
Yokkaichi in Japan
Residence
Gross floor space: 338m²

**Layout facility**
Used for cooling/Heating
Two GSHPs installed
Four BHE installed
Eight hours per day operates

**Logging field data**
HP operation
Pipes surface temp.
Heat source water (Temp&Flow)
Logging interval is 1 min.

Diagram of BHE in GSHP

- Double U-tube type
- Concentric tube type

Heat source water: Ethylene glycol solution, 20% wt.
Numerical model of BHEs

Domain of calculation

Table 1: Thermal peculiarity of soil and backfill (Watanabe et al., 1983)

<table>
<thead>
<tr>
<th>Thermal Peculiarity</th>
<th>Heat Conductivity (W/mK)</th>
<th>Volumetric Specific heat (kJ/m³K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand gravel</td>
<td>0.62</td>
<td>1,580</td>
</tr>
<tr>
<td>Loam</td>
<td>0.70</td>
<td>3,260</td>
</tr>
<tr>
<td>Clay</td>
<td>1.74</td>
<td>2,510</td>
</tr>
<tr>
<td>Sand</td>
<td>1.39</td>
<td>2,009</td>
</tr>
<tr>
<td>Mortar</td>
<td>1.40</td>
<td>2,222</td>
</tr>
</tbody>
</table>

Energy balance formula for the given block of soil

\[
c_z \rho_s \frac{\partial \theta_s}{\partial t} = \lambda_s \left( \frac{\partial^2 \theta_s}{\partial x^2} + \frac{\partial^2 \theta_s}{\partial y^2} + \frac{\partial^2 \theta_s}{\partial z^2} \right)
\]

Energy balance formula for the ground surface

\[-\lambda_z \frac{\partial \theta_s}{\partial y} \bigg|_{y=0} = \alpha_{zz} (\theta_{zz} - \theta_w) + aJ - a_T \tau \mathrm{d}n\]
Simplification of calculation model of BHE

Heat transmission area is same
Backfill volume is same
Numerical model of BHEs

Domain of calculation

3D Transient model account for sensible heat only

Simulation conditions
    Ambient : Field Measurement data
    Heat source water temp. and flow : Field data
    Solar radiation : Meteorological data

Validation (Double U-tube Type)

Heat injection term (Sep.)

<table>
<thead>
<tr>
<th></th>
<th>Meas.</th>
<th>Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Inlet Temp.</td>
<td>38.2 °C</td>
<td></td>
</tr>
<tr>
<td>Ave. Outlet Temp.</td>
<td>31.8 °C</td>
<td>33.5 °C</td>
</tr>
<tr>
<td>Sum of heat trans.</td>
<td>2.3MWh</td>
<td>1.68MWh</td>
</tr>
</tbody>
</table>

Mean diff. 1.7 °C  -27%

Heat extraction term (Jan.)

<table>
<thead>
<tr>
<th></th>
<th>Meas.</th>
<th>Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Inlet Temp.</td>
<td>7.5 °C</td>
<td></td>
</tr>
<tr>
<td>Ave. Outlet Temp.</td>
<td>10.4 °C</td>
<td>11.0 °C</td>
</tr>
<tr>
<td>Sum of heat trans.</td>
<td>0.23MWh</td>
<td>0.29MWh</td>
</tr>
</tbody>
</table>

Mean diff. 0.6 °C  +26%
Validation (Concentric tube Type)

Heat injection term (Sep.)

<table>
<thead>
<tr>
<th></th>
<th>Meas.</th>
<th>Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Inlet Temp.</td>
<td>30.8 °C</td>
<td></td>
</tr>
<tr>
<td>Ave. Outlet Temp.</td>
<td>26.5 °C</td>
<td>26.8 °C</td>
</tr>
<tr>
<td>Sum of heat trans.</td>
<td>1.09 MWh</td>
<td>1.03 MWh</td>
</tr>
</tbody>
</table>

Mean diff. 0.3°C  -6%

Heat extraction term (Jan.)

<table>
<thead>
<tr>
<th></th>
<th>Meas.</th>
<th>Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Inlet Temp.</td>
<td>3.6 °C</td>
<td></td>
</tr>
<tr>
<td>Ave. Outlet Temp.</td>
<td>6.4 °C</td>
<td>6.2 °C</td>
</tr>
<tr>
<td>Sum of heat trans.</td>
<td>1.93 MWh</td>
<td>1.79 MWh</td>
</tr>
</tbody>
</table>

Mean diff. 0.2°C  -7%
Conclusion

Produced numerical model could approximate the thermal behavior of the double-U type BHE, and successfully captured the trend of that when heat pump is operated.

With regard to concentric type BHE, we confirmed a close agreement between prediction and measurement.

we will continue to study and evaluate the operating performance of GSHP in consideration of the heat pump operating characteristics and the load profile changes on the building.