BOREHOLE INSTALLATIONS
OR
AIR TO WATER HEAT PUMPS.
WHAT TO USE AND WHERE.

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Why examine this?

• In Norway there is consensus that the most economical heat pump solution is reached by using ground loop heat exchangers (Borehole installations).
• Backed by “I believe...“ or “Mushroom” theory.
• “Mushroom” theory. Lives in dark and feeds on horseshit.
• Widespread consensus based on “I believe...” should arise suspicion.
Where are we examining?
Where are we examining?
Where are we examining?

1 760 km.
As the crow flies:
Belgrade to Oslo
Climates used in the assessments.

<table>
<thead>
<tr>
<th>Location</th>
<th>Design ambient temp. [°C]</th>
<th>Annual mean ambient temp. [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bergen</td>
<td>-12</td>
<td>8.2</td>
</tr>
<tr>
<td>Karaksjok</td>
<td>-40</td>
<td>-1.5</td>
</tr>
<tr>
<td>Oslo</td>
<td>-20</td>
<td>6.0</td>
</tr>
<tr>
<td>Røros</td>
<td>-30</td>
<td>3.8</td>
</tr>
<tr>
<td>Tromsø</td>
<td>-15</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Temperture duration

Ambient temperature [°C]

Location: Bergen
Heat rate demand and heat energy demand.

Design heat demands at different ambient temperatures.

- Transmission and infiltration heat rate loss [kW]
- Ventilation heat rate demand in AHU [kW]
- Ventilation heat rate demand in room [kW]
Heat rate demand and heat energy demand.

-20°C

204 kW

538 kW

ε = 0,80

20°C

16200000 m³/80%

ε = 0,80

17 500 m²

400 kW

306 kW

138 kW

298 kW

80% Presence

850 Work places

Light: 8 W/m²

Misc. 10 kW

80 W/person

150 W/PC

17 500 m²

306 kW

22°C

20°C

138 kW

298 kW

ε = 0,80

16200000 m³/80%
Heat rate demand and heat energy demand.

### Annual Heating energy demand [kWh]

- **Bergen**: 797 267
- **Karasjok**: 1 825 357
- **Oslo**: 1 005 839
- **Røros**: 1 330 858
- **Tromsø**: 1 245 137

### Design heat rate demand [kW]

- **Bergen**: 677
- **Karasjok**: 1 377
- **Oslo**: 911
- **Røros**: 1 144
- **Tromsø**: 794
Heat pump configurations

Three system configurations calculated
- using three different compressor makes,
  - Bitzer generic recip and screw, Sabroe generic SMC recip
  - Five different locations => 45 different data sets
Heat pump design criteria

- Heat pump performance determined from Sabroe Generic giving an energy coverage of 95% in a borehole configuration.
- The performance differences stem mostly from the different operating ranges.

<table>
<thead>
<tr>
<th>Location</th>
<th>Heating system design demand (kW)</th>
<th>Heat pump design performance (kW)</th>
<th>Design evaporation temperature (°C)</th>
<th>Design condensation temperature (°C)</th>
<th>Heat pump process COP</th>
<th>Evaporator performance</th>
<th>Compressor swept volume (m³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bergen</td>
<td>677</td>
<td>174</td>
<td>-2.3</td>
<td>47.4</td>
<td>4.52</td>
<td>4.61</td>
<td>4.11</td>
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<tr>
<td>Karasjok</td>
<td>1377</td>
<td>456</td>
<td>-12.0</td>
<td>40.8</td>
<td>3.96</td>
<td>4.09</td>
<td>3.82</td>
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<tr>
<td>Oslo</td>
<td>911</td>
<td>217</td>
<td>-4.5</td>
<td>49.3</td>
<td>4.13</td>
<td>4.21</td>
<td>3.78</td>
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<tr>
<td>Røros</td>
<td>1144</td>
<td>282</td>
<td>-6.7</td>
<td>47.1</td>
<td>4.07</td>
<td>4.15</td>
<td>3.78</td>
</tr>
<tr>
<td>Tromsø</td>
<td>794</td>
<td>223</td>
<td>-7.1</td>
<td>46.6</td>
<td>4.06</td>
<td>4.15</td>
<td>3.78</td>
</tr>
</tbody>
</table>
Heat pump energy coverage

Compressor Operating Ranges

- Bitzer Generic Recip Operating range
- Sabroe Generic Recip Operating range
- Bitzer Generic Screw Operating range

$T_{\text{cond}}$ [°C] vs $T_{\text{evap}}$ [°C]

-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20

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Heat pump efficiency. Compressor

- Bitzer generic isentropic and volumetric efficiencies assessed from Bitzer polynomials available from their calculation software.
- Sabroe generic isentropic and volumetric efficiencies assessed from Sabroe source code supplied by Uffe Christensen, head of COMP1 development and maintenance. (Dead at present. Very little hope of getting better)
- Correction of isentropic efficiency at off-design is based on functions developed from Sabroe source code for recip and generic screw compressors.
Heat pump efficiency. Compressor power train

- Motor efficiency is found from an IE3-class 2 pole 50Hz motor.
- Off design efficiency is compensated.
- Calculation efficiency is set as IE1 motor, in order to compensate for VSD drive efficiency.
Energy demand for heat extraction

- Pump demand for borehole installation 150 W/well * 8760h
- Pump demand for intermediate glycol circuit in dry cooler installations 185 W/kW heat * actual runtime
- Fan power found from Güntner GPC 2015 software

![Graph showing fan power vs evaporator performance]
Seasonal Coefficients Of Performance (SCOP)

- \( SCOP_{HEAT\ PUMP} = \frac{Q_{FROM\ HEAT\ PUMP}}{W_{COMP.\ POWER\ TRAIN}} \)

- \( SCOP_{INCL\ EXTRACTION} = \frac{Q_{FROM\ HEAT\ PUMP}}{W_{COMP.\ POWER\ TRAIN} + W_{EXTRACTION}} \)

- \( SCOP_{TOTAL\ SYSTEM} = \frac{Q_{TOTAL\ HEAT\ DEMAND}}{W_{COMP.\ POWER\ TRAIN} + W_{EXTRACTION} + Q_{AUX}} \)
Seasonal Coefficients Of Performance (SCOP)
Energy savings

Relative energy saving

Bergen, Karasjokk, Oslo, Røros, Tromsø

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Investment

- 12 500 €/well.
  - One well supplies 6 kW to the evaporator. With design COPs ranging from 3.8 to 4.6 this results in a specific investment in the range of 1 540 €/kW to 1 620 €/kW.
- Heat pump unit.
  - Standard unit equipment.
  - Investment estimated from other projects and price lists.
  - Evaporator cost estimated to 15% of total unit cost.
- Evaporator. Air heated evaporator cost estimated by Güntner GPC 2015 software. From this 15% HP unit cost is subtracted
  - Dry cooler estimated to 75% of the air heated evaporator cost. Lighter construction.
    - Pipe work from dry cooler to estimated to 35 000 €.
    - Pump investment from experience.
Cost of ownership

Annual costs of ownership.

Energy cost 0.1 €/kWh

- Bitzer Generic Recip
- Bitzer Generic Screw
- Sabroe Generic Recip
- Sabroe Generic Screw

Borehole Dry cool Air evap Borehole Dry cool Air evap Borehole Dry cool Air evap Borehole Dry cool Air evap

Bergen Karasjok Oslo Røros Tromsø

- Annual cap. cost
- Annual energy cost
Simple payback boreholes
Conclusions

- The borehole installation will provide a more stable heat source
  - If you are able to recharge the installation during the cooling season.
  - In cold areas, the summer cooling demand is virtually non-existant, so another re-heat source must be provided.
- The borehole installation is NOT the most economical efficient solution.
- The most economical solution seems to be the air-to-water heat pump, using air directly on the evaporator.
- This solution however will probably mean a big charge.
- This heat pump can usually not be used as part of the cooling installations.
- However, the presentation “INTERNAL REVERSIBLE AMMONIA AIR-TO-WATER HEAT PUMP / CHILLER” will give some hints on what you can do.
Thank you for staying awake.