Economic and Energy Performance of Heating and Ventilation Systems in Norwegian Detached Houses renovated towards NZEB

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Economic and Energy Performance of Heating and Ventilation Systems in Norwegian Detached Houses renovated towards NZEB

• Research within the OPPTRE project
  • OPPTRE led by SINTEF supported by the RCN
  • Deep energy-retrofit of Norwegian single-family detached houses
  • “Energy renovation of detached wooden house towards nearly ZEB”

• Context:
  • The building envelope has been upgraded significantly
  • Energy measures on envelope and HVAC should ideally be analyzed together in a holistic way
  • In practice, design on the envelope decided first and the HVAC solution is selected in a second step

• Research question:
  • Compare performance of different HVAC all-electric solutions in terms of life cycle costs (LCC) and energy efficiency
  • HVAC solutions are based on heat pump technologies
Methodology

• Two houses from the OPPTRE architecture competition used as case
  • “Hus-i hage”, Malvik, 1957
  • “1+1=3”, Kristiansand, 1972
  • Different size, shape, construction year
  • One has cold attic and studio apartment

• Different HVAC combinations are evaluated

• Detailed building performance simulations
  • Using IDA ICE software
  • Multi-zone for realistic energy coverage factor
  • System SPF compared with literature
  • NS-NSPEK 3031 input data

• Economic assessment
  • NS-EN 15459-1:2017
  • Uncertainty in investment costs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation period (TC) [years]</td>
<td>20</td>
</tr>
<tr>
<td>Inflation rate [%]</td>
<td>2</td>
</tr>
<tr>
<td>Real discount rate [%]</td>
<td>3</td>
</tr>
<tr>
<td>Electricity price [NOK/kWh]</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Parameters for calculating the economic performance
Investment costs

- Most LCC analysis do not consider uncertainty on investment costs
  - In scientific publications

- Collection of costs from several references
  - Costs of current Norwegian market
  - Most of the costs were collected directly from suppliers, building companies or their webpages
  - Where this was not possible, generic costs from reports and statistics were used

- Creating a cost range
  - Min, mean and max values
Defined 3 different insulation levels

- **TEK10**
- **OPPTRE**: close to proposals in architecture competition
- **PASSIV**: passive house requirement for components

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Existing Kristians.</th>
<th>Existing Malvik</th>
<th>TEK10</th>
<th>OPPTRE</th>
<th>PASSIV</th>
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</thead>
<tbody>
<tr>
<td>U-value external wall</td>
<td>W/(m².K)</td>
<td>0.45</td>
<td>0.44</td>
<td>0.22</td>
<td>0.18</td>
<td>0.11</td>
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<tr>
<td>U-value roof</td>
<td>W/(m².K)</td>
<td>0.5</td>
<td>0.3</td>
<td>0.18</td>
<td>0.14</td>
<td>0.08</td>
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<tr>
<td>U-value basement wall to ground</td>
<td>W/(m².K)</td>
<td>0.87</td>
<td>3.5</td>
<td>0.33</td>
<td>0.2</td>
<td>0.11</td>
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<tr>
<td>U-value external floor</td>
<td>W/(m².K)</td>
<td>0.54</td>
<td>4.3</td>
<td>0.3 (4.3*)</td>
<td>0.18 (4.3*)</td>
<td>0.11</td>
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<tr>
<td>U-value internal walls</td>
<td>W/(m².K)</td>
<td>0.47</td>
<td>0.6</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
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<tr>
<td>U-value windows and doors</td>
<td>W/(m².K)</td>
<td>2.6</td>
<td>2.6</td>
<td>1.6</td>
<td>1.0</td>
<td>0.8</td>
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<tr>
<td>Normalized thermal bridge value</td>
<td>W/(m².K)</td>
<td>0.07</td>
<td>0.07</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
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<tr>
<td>Infiltration</td>
<td>h⁻¹</td>
<td>6.0</td>
<td>6.0</td>
<td>3.0</td>
<td>1.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*U-value 4.3 in the Malvik house
Heating and ventilation packages

- **Combinations**
  - Heating (SH and DHW)
  - Ventilation

- **Heat pump type**
  - Air-to-air (A2A)
  - Air-to-water (A2W)
  - Ground source (GSHP)
  - Compact: balanced mechanical ventilation with heat recovery integration in HP unit
  - Extract air heat pump (EAHP)

<table>
<thead>
<tr>
<th>Combination</th>
<th>Space-heating (SH)</th>
<th>Hydronic distribution</th>
<th>DHW</th>
<th>Ventilation</th>
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</thead>
<tbody>
<tr>
<td>BalVent</td>
<td>Electric panel heaters, electric floor heating in bathroom.</td>
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<td>Electric boiler</td>
<td>Balanced mechanical</td>
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<td>A2A</td>
<td>Air-to-air heat pump in living room. Electric panel heaters, electric floor heating in bathroom.</td>
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<td>A2W</td>
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<td>Air-to-water HP</td>
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<td>GSHP</td>
<td>Ground source heat pump (GSHP) where the borehole heat exchanger should be created.</td>
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<td>GSHP</td>
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<td>CHP</td>
<td>Compact heat pump unit for ventilation air heating. Electric panel heaters, electric floor heating in bathroom.</td>
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<td>Compact HP</td>
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<td>CHPcomb</td>
<td>Compact heat pump.*</td>
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<td>EAHPDHW</td>
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<td>Extract air heat pump (EAHP).</td>
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<td>EAHP</td>
<td>Extraction mechanical</td>
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</table>

*The simulated version can also use outdoor air as heat source when heat from ventilation extract is not sufficient.
Heat pump efficiency

- Energy coverage factor
  - For space-heating and DHW
  - Uncertainty for A2A heat pump due to heat distribution and occupant behaviour
  - High coverage obtained using hydronic distribution (floor heating or/and convectors)

- Seasonal Performance Factor (SPF)
  - System SPF ($SPF_4$)
  - Higher for high coverage factor

Energy coverage factor of the heat pump in both houses.

Seasonal performance factor for heat pump system in both houses.
Heat pump efficiency

- Compare SPF in cold climate from literature
  - Some studies from warmer climate (Germany, Ireland)

<table>
<thead>
<tr>
<th>Hp type</th>
<th>Study</th>
<th>Numb. of HP</th>
<th>Building</th>
<th>Location</th>
<th>SPF low</th>
<th>SPF high</th>
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<td></td>
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<td>Switserl. Scotl.</td>
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<td>O Sullivan et al (38)</td>
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<td></td>
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<td>Shirani et al (39)</td>
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<td>Extract air</td>
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<td></td>
<td>Sweden</td>
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<td>Multi-fam. Estonia</td>
<td>1.91</td>
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<td>Thalfeldt et al (41)</td>
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<td>Multi-fam.</td>
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<td>Sweden</td>
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<td>2021</td>
<td>Saini et al (43)</td>
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</table>
Investment of HVAC combinations

• Investment for energy measures on building envelope significantly more expansive
  • But contribute to indoor environmental quality

• Three ranges of investment
  • Lower: BalVent, A2A, EAHPDHW
  • Medium: A2Asolar, CHP, EAHPcomb
  • Higher: A2W, CHPcomb, GSHP
Payback time

- Reference is the extract mechanical ventilation with direct electric heating

- Scenario
  - Baseline
  - Economic support from government not included

- Payback time trends
  - Above 10 years
  - Below 20 years for most low investment combinations
  - Around 20 years for medium investment combinations
  - Above 20 years for high investment combinations
Payback time

• Strongly influenced by the electricity price
  • Higher prices make most payback times < 20 years
Global costs

- Scenario
  - Baseline
  - Economic support from government not included

- Global costs trends
  - Not influence by insulation level
  - Uncertainty on investment important
  - Low investment combinations leads to lower global cost
  - Medium investment combinations also have lower global costs but with a significant decrease in energy use
  - High investment combinations have higher global costs (< 1000 NOK/m²) but even lower energy use
Global costs

• Scenario
  • Baseline
  • Economic support from government not included

• Global costs trends
  • Not influence by insulation level
  • Uncertainty on investment important
  • Low investment combinations leads to lower global cost
  • Medium investment combinations also have lower global costs but with a significant decrease in energy use
  • High investment combinations have higher global costs (< 1000 NOK/m²) but even lower energy use
Global costs

- Strongly influenced by the electricity price
- With higher electricity prices (2.0 NOK/kWh)
  - Combinations with medium investment have lowest total costs
  - Compact combi heat pump (CHPcomb) has low total costs with 55 to 72 kWh/m².year electricity use
Costs when hydronic distribution system is already existing

Specific investment costs for HVAC combinations, with hydronic distribution existing.

Specific investment costs for HVAC combinations. Baseline case.
Costs when hydronic distribution system is already existing

- Red: TEK10
- Blue: OPPTRE
- Green: PASSIVE
Effect of new power tariffs

New proposed power grid tariffs and old tariffs are analysed for Glitre, Elvia and Nettselskapet.

Results:
- Power tariffs induce lower total energy costs
- New tariff makes little difference
- Difference between companies larger than effects of changing to new tariff

<table>
<thead>
<tr>
<th>Power cost (NOK/month)</th>
<th>Existing</th>
<th>Power limit (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No limit</td>
<td>2</td>
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<tr>
<td>Glitre energi</td>
<td>135</td>
<td>135</td>
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<tr>
<td>Elvia</td>
<td>115</td>
<td>130</td>
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<tr>
<td>Nettselskapet</td>
<td>365</td>
<td>62.5</td>
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</tbody>
</table>

Monthly peak power based fee for the analysed grid tariffs, based on maximum hourly-averaged power for preceding month.

Total specific energy costs for Kristiansand house over 20 years, with different electricity tariffs. GSHP in filled and A2A shaded.
Conclusions

• For the deep-retrofit scenarios considered, the relative performance between HVAC solutions is not affected much by the insulation level.

• Many solutions with medium and higher investments have a payback back time close to the technical lifetime of the equipment, meaning 20 years which is critical.
  • The higher the insulation level, the longer the payback time

• Global costs
  • Uncertainty on investment costs is important and affects the relative performance between HVAC solutions. The span in investment costs for HVAC investments result in significant spans in global costs.
  • Solutions with lower investment costs often lead to lower total costs but higher energy use.
  • However, solutions with a medium investment cost lead to a significant reduction of the energy use for a small increase of the total costs. Improvement of the cost effectiveness of these technologies (reduced investment costs, grants) would unlock a large energy saving potential.

• Hydronic system enables a higher energy coverage factor, leading to a higher system SPF. However, hydronic system is seldom installed in most existing Norwegian wooden houses. This penalizes technologies like ASHP and GSHP.

• Introduction of new grid tariffs in Norway to limit peak power will not have a large impact on cost effectiveness of HVAC solutions and their relative performance.

• The governmental grants have currently a limited impact on the relative cost performance of HVAC solutions.
THANK YOU
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