Residential heat pumps in the future Danish energy system

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Residential heat pumps in the future
Danish energy system

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Systems Analysis division, Department of Management Engineering, Technical University of Denmark
Elements of future Danish energy system

- Wind power
- District heating
- Residential heat pumps, biomass boilers and solar heating
- Heat savings in buildings
- Demolition of existing and construction of energy-efficient buildings
Residential heat pumps in the previous studies

• Oil and natural gas boilers are switching to residential HPs in 2025 (Münster et al. 2012)

• Expansion of district heating around cities and towns and residential HPs (Lund et al., 2010, Möller and Lund, 2010)

• Expansion of district heating based on biomass and large HPs and residential HPs, solar heating and biomass boilers (IDA's Climate Plan 2009)

• District heating, solar heating and residential heat pumps in Aalborg and Frederikshavn (Østergaard et al., 2010 and Østergaard, 2012)
Benefits of using residential heat pumps

• Contribute to the integration of wind power and PVs – provide flexibility and reduce excess power production

• Reducing fuel consumption, CO$_2$ emissions and total system costs

• Favoured in high health impact areas
TIMES-DTU – time definition

- No chronological values
- 32 time-slices and 10 model-years

<table>
<thead>
<tr>
<th>Time period</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
<th>P10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start year</td>
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<td>2011</td>
<td>2014</td>
<td>2018</td>
<td>2023</td>
<td>2028</td>
<td>2033</td>
<td>2038</td>
<td>2043</td>
<td>2048</td>
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<tr>
<td>End year</td>
<td>2010</td>
<td>2013</td>
<td>2017</td>
<td>2022</td>
<td>2027</td>
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<td>2037</td>
<td>2042</td>
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<td>3</td>
<td>4</td>
<td>5</td>
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<td>5</td>
<td>5</td>
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<tr>
<td>Representative year</td>
<td>2010</td>
<td>2012</td>
<td>2015</td>
<td>2020</td>
<td>2025</td>
<td>2030</td>
<td>2035</td>
<td>2040</td>
<td>2045</td>
<td>2050</td>
</tr>
</tbody>
</table>
TIMES-DTU – geographical definition

- Two regions – East and West Denmark
- Subdivisions into Central, Decentral and Individual
TIMES-DTU – geographical definition
TIMES-DTU – geographical definition
TIMES-DTU model – residential buildings

- Region – DKE and DKW
- Construction period – before 1972, after 1972 and new buildings
- Location relative to existing district heating areas – Central, Decentral and Individual
- Building use – Single-family and Multi-family
- Heat savings, construction, demolition
Supply of heat and DHW in TIMES-DTU

District heating

Primary energy → District heat → Heat from pipeline

- HO and CHP plants
- Expanded DH network
- Existing DH network
- New heat exchangers
- Existing heat exchangers

Residential heat and DHW

Residential individual heating

Primary energy → Residential heat boilers

Heat savings
TIMES-DTU model – Modelling of residential heat pumps

- Three types of residential HPs are modelled
- Variable COPs
- Spatial constraints
- Other techno-economic parameters

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Air-to-air</td>
<td>2015</td>
<td>4.02</td>
<td>20</td>
<td>0.06</td>
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<td>0.12</td>
<td>4.02</td>
<td>20</td>
<td>0.06</td>
<td>0</td>
<td>0.12</td>
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<td></td>
<td>2020</td>
<td>3.87</td>
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<td></td>
<td>2030</td>
<td>3.58</td>
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<td>Air-to-water</td>
<td>2015</td>
<td>9.69</td>
<td>20</td>
<td>0.10</td>
<td>0</td>
<td>0.20</td>
<td>7.45</td>
<td>20</td>
<td>0.01</td>
<td>0</td>
<td>0.20</td>
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<tr>
<td></td>
<td>2020</td>
<td>8.94</td>
<td></td>
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<td>7.45</td>
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<td>8.94</td>
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<td>6.71</td>
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<td></td>
<td>6.71</td>
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<tr>
<td>Brine-to-water</td>
<td>2015</td>
<td>12.67</td>
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<td>2020</td>
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<td>10.43</td>
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<td>6.71</td>
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<td></td>
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</table>
Temperature-dependant COP

Air-source heat pumps

Ground-source heat pumps

COPs are expressed as a linear function of a temperature difference between air/water output and ambient temperature.
Temperature regions

Soil temperature regions in Denmark

Air temperature regions in Denmark
Temperatures and calculated COPs

<table>
<thead>
<tr>
<th>Type of heat pump</th>
<th>Region</th>
<th>Seasons</th>
<th>Yearly average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>Summer</td>
</tr>
<tr>
<td>GSHP</td>
<td>Denmark</td>
<td>3.05</td>
<td>3.95</td>
</tr>
<tr>
<td>ASHP</td>
<td>East Denmark</td>
<td>2.72</td>
<td>3.30</td>
</tr>
<tr>
<td>ASHP</td>
<td>West Denmark</td>
<td>2.70</td>
<td>3.22</td>
</tr>
</tbody>
</table>

Hourly changes of air and soil temperatures

Hourly changes of COPs

Seasonal COPs
Spatial constraints

• Maybe there is not enough space to install ground source heat pumps

\[
COP = \frac{W_h}{W_e} = \frac{W_h}{W_{h-W_{gr}}} \\
W_h = \frac{COP}{COP-1} \cdot W_{gr} \\
W_h = P_{h,spec} \cdot A_{av} \cdot k_{area} \cdot T_{fih} \cdot \frac{COP_{av}}{COP_{av} - 1}
\]
Spatial constraints - results

- A Heat pump can only supply its own demand, not the neighbours

- Example 1: Heat pump can cover 100 MWh, building's demand is 50 MWh → Heat pump can produce at most 50 MWh

- Example 2: Heat pump can cover 100 MWh, building's demand is 150 MWh → Heat pump can produce at most 100 MWh

<table>
<thead>
<tr>
<th>Region</th>
<th>Building type</th>
<th>Useable area (km²)</th>
<th>Heat demand (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKE</td>
<td>Single-family</td>
<td>2194</td>
<td>4.8</td>
</tr>
<tr>
<td>DKE</td>
<td>Multi-family</td>
<td>37</td>
<td>0.7</td>
</tr>
<tr>
<td>DKW</td>
<td>Single-family</td>
<td>6402</td>
<td>6.7</td>
</tr>
<tr>
<td>DKW</td>
<td>Multi-family</td>
<td>45</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Analysed scenarios

• Base scenario includes politically agreed renewable energy targets declared in:
  - At least 50% of electricity consumption needs to be produced from wind power starting from 2020.
  - Use of fossil fuels is forbidden in the production of electricity and heat starting from 2035.

• NoIHP (No Installation of Heat Pumps) – The only difference from Base scenario is that installation of residential ASHPs and GSHPs is not allowed.

• NoCIHP (No Constrains on Installation of Heat Pumps) – The only difference from Base scenario is that installation of residential GSHPs is unconstrained.
Results – Electricity production

Electricity production divided by fuels

- Import
- Export
- Onshore wind
- Offshore wind
- PV
- Biomass
- Biosynth. nat. gas
- Natural gas
- Waste
- Coal
Results – Heat supply

Heat delivered to residential consumers

Heat delivered to residential consumers from individual heating sources
Results – total system costs

Sum of total undiscounted system costs over the analysed period

- Base
- NoHP
- NoCIHP

- Salvage
- Export/Import
- Fuel
- Var. O&M
- Fix. O&M
- Investment

Sum of total undiscounted system over the analysed period
Results – environmental emissions

Small differences among scenarios in emissions
Results – fuel consumption

Small differences among scenarios in fuel consumption
## Sensitivity analysis

<table>
<thead>
<tr>
<th>Sensitivity action</th>
<th>System costs</th>
<th>CO₂ emissions</th>
<th>Onshore wind production</th>
<th>Offshore wind production</th>
<th>DH production</th>
<th>GSHP production</th>
<th>ASHP production</th>
<th>Biomass boilers production</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 10 % investment costs of ASHPs</td>
<td>-0.4%</td>
<td>0.4%</td>
<td>0.0%</td>
<td>-1.8%</td>
<td>-5.4%</td>
<td>-21.7%</td>
<td>38.9%</td>
<td>-22.7%</td>
</tr>
<tr>
<td>- 10 % investment costs of GSHPs</td>
<td>-0.1%</td>
<td>0.1%</td>
<td>0.0%</td>
<td>-0.9%</td>
<td>-0.9%</td>
<td>53.2%</td>
<td>2.9%</td>
<td>-13.3%</td>
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<tr>
<td>- 10 % investment costs of wind turbin.</td>
<td>-2.9%</td>
<td>0.3%</td>
<td>0.0%</td>
<td>19.6%</td>
<td>1.2%</td>
<td>8.2%</td>
<td>3.2%</td>
<td>-25.0%</td>
</tr>
<tr>
<td>- 10 % price of biomass</td>
<td>-1.1%</td>
<td>-1.6%</td>
<td>0.0%</td>
<td>-3.4%</td>
<td>-3.9%</td>
<td>-23.9%</td>
<td>-15.6%</td>
<td>94.6%</td>
</tr>
<tr>
<td>- 20 % price of biomass</td>
<td>-2.5%</td>
<td>-5.5%</td>
<td>0.0%</td>
<td>-7.1%</td>
<td>-14.0%</td>
<td>-41.6%</td>
<td>-39.7%</td>
<td>288.8%</td>
</tr>
<tr>
<td>- 20 % inv. costs of DH expansion</td>
<td>-0.2%</td>
<td>0.2%</td>
<td>0.0%</td>
<td>-0.7%</td>
<td>0.9%</td>
<td>-1.5%</td>
<td>-5.4%</td>
<td>2.4%</td>
</tr>
<tr>
<td>+ 10 % investment costs of ASHPs</td>
<td>0.2%</td>
<td>-0.4%</td>
<td>0.0%</td>
<td>-1.1%</td>
<td>2.0%</td>
<td>-1.1%</td>
<td>-26.8%</td>
<td>41.8%</td>
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<tr>
<td>+ 10 % investment costs of GSHPs</td>
<td>0.0%</td>
<td>-0.1%</td>
<td>0.0%</td>
<td>-0.2%</td>
<td>0.4%</td>
<td>-54.4%</td>
<td>2.3%</td>
<td>10.4%</td>
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<td>+ 10 % investment costs of wind turbin.</td>
<td>2.5%</td>
<td>2.5%</td>
<td>0.0%</td>
<td>-14.0%</td>
<td>-1.0%</td>
<td>-24.1%</td>
<td>-3.2%</td>
<td>29.4%</td>
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<tr>
<td>+ 10 % price of biomass</td>
<td>0.7%</td>
<td>2.2%</td>
<td>0.0%</td>
<td>-0.6%</td>
<td>2.0%</td>
<td>12.5%</td>
<td>0.7%</td>
<td>-33.7%</td>
</tr>
<tr>
<td>+ 20 % price of biomass</td>
<td>1.3%</td>
<td>3.9%</td>
<td>0.0%</td>
<td>1.0%</td>
<td>2.5%</td>
<td>8.5%</td>
<td>-0.2%</td>
<td>-36.1%</td>
</tr>
<tr>
<td>+ 20 % inv. costs of DH expansion</td>
<td>0.2%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>-0.2%</td>
<td>-1.5%</td>
<td>1.4%</td>
<td>10.2%</td>
<td>-5.9%</td>
</tr>
<tr>
<td>reduction factor ( k_{area} = 0.8 )</td>
<td>-0.01%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>-0.4%</td>
<td>23.0%</td>
<td>-1.5%</td>
<td>-0.5%</td>
</tr>
<tr>
<td>Fixed COPs over whole year</td>
<td>-0.2%</td>
<td>-0.3%</td>
<td>0.0%</td>
<td>-2.0%</td>
<td>-1.6%</td>
<td>-1.5%</td>
<td>9.5%</td>
<td>-2.9%</td>
</tr>
<tr>
<td>- 50 % out of total heat saving potential</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.0%</td>
<td>-0.1%</td>
<td>-1.8%</td>
<td>0.2%</td>
<td>12.8%</td>
<td>-8.4%</td>
</tr>
<tr>
<td>Forbidding heat savings</td>
<td>8.5%</td>
<td>0.9%</td>
<td>0.0%</td>
<td>3.2%</td>
<td>4.8%</td>
<td>3.9%</td>
<td>82.2%</td>
<td>45.5%</td>
</tr>
</tbody>
</table>
Conclusions and future work

• Improved modelling makes a difference

• Residential HPs produce of 66-70 % of heat from individual heating sources, i.e. 24-28 % of total heat demand after 2035.

• Danish energy system can function without investments in residential HPs - total system costs increase by 16 % and biomass use by 70 %.

• Parameters $P_{h,spec}$ and $k_{area}$ should be explored in more details

• ASHPs in multi-storey buildings – noise as a by-product

• More detailed COPs

• Role of residential HPs in the light of accelerated introduction of heat savings
Thank you for your attention

• Questions
• Answers
• Comments
• Suggestions