Centralized and decentralized solar heating systems suitable for the future energy system

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Denmark 2050: Independent of fossil fuels

Wind energy:
2017, 43% of electricity consumption
2020: 50% of increased electricity consumption (incl. transport, heat pumps, …)

Solar heating:
2030: 15% of decreased heating demand
2050: 40% of decreased heating demand - 80% of this by solar heating plants & 20% individual systems
How will solar heating systems achieve a good interplay with the energy system?

Solution:
Combined technologies and **smart heat storage** interacting with the electricity grid ...

**Smart heat storage:**
- Gives flexibility
- Makes combinations of technologies possible
- Use cheap electricity
Solar heating plant - principle

Solar collector field
Heat exchanger
District heating boiler plant
Consumers
Solar heating plants

2013: Dronninglund 37,573 m²

2012: Marstal 33,365 m²

2015: Vojens 70,000 m²

2016: Silkeborg 156,694 m²
300 solar heating plants > 500 m²
110 in Denmark, 37%
1,648,383 m² in operation
1,317,635 m² in Denmark, 80%!
Solar heating plants in Denmark

Average solar collector area per plant

<table>
<thead>
<tr>
<th>Year</th>
<th>Total district heating, PJ/year</th>
<th>Solar district heating, PJ/year</th>
<th>Solar district heating, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>132</td>
<td>0.29</td>
<td>0.2</td>
</tr>
<tr>
<td>2012</td>
<td>136</td>
<td>0.45</td>
<td>0.3</td>
</tr>
<tr>
<td>2013</td>
<td>135</td>
<td>0.63</td>
<td>0.5</td>
</tr>
<tr>
<td>2014</td>
<td>122</td>
<td>0.90</td>
<td>0.7</td>
</tr>
<tr>
<td>2015</td>
<td>128</td>
<td>1.31</td>
<td>1.0</td>
</tr>
<tr>
<td>2016</td>
<td>128</td>
<td>2.05</td>
<td>1.6</td>
</tr>
<tr>
<td>2017</td>
<td>128</td>
<td>2.57</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Planned plants: 371.513 m²
Investment cost per m² collector

Solar collector field price

Heat price versus year of construction

- No storage or short term storage
- Long term storage
Solar heating plants’ interaction with variable electricity production improved and cost efficiency hardly influenced by:

High solar fractions/long term heat storage due to:

• Simple heat storage technologies
• Large heat storages with small heat losses and low costs per volume
• Advantages by combining technologies
• Interplay with liberal electricity market
Cheap storage technology: Water pit and borehole storage

Heat capacity per volume:
- Water: 4.1 MJ/Km$^3$
- Soil: About 2.7 MJ/Km$^3$
Water pits

Marstal 75,000 m³

Vojens 200,000 m³

Dronninglund 62,000 m³

Gram 110,000 m³
LARGE SYSTEMS $\rightarrow$ small storage losses & lower specific costs

Surface area per volume
(Cylinder, Radius = Height)

Cost per equivalent m$^3$

Make it big

1.2 $\rightarrow$ 0.1 $\Rightarrow$ Factor 12!

500 $\rightarrow$ 20 $\Rightarrow$ Factor 25!

Water pits for seasonal heat storage with water volumes $> 60,000$ m$^3$: Yearly heat loss $< 10\%$

Source: SOLITES
## Measurements

<table>
<thead>
<tr>
<th></th>
<th>Borehole storage, Brædstrup</th>
<th>Water pit storage, Marstal</th>
<th>Water pit storage, Dronninglund</th>
<th>Water pit storage, Gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>19000 m³ soil, corresponding to about 12000 m³ water</td>
<td>75000 m³ water</td>
<td>62000 m³ water</td>
<td>110000 m³ water</td>
</tr>
<tr>
<td>Maximum storage temperature</td>
<td>50°C</td>
<td>90°C</td>
<td>90°C</td>
<td>90°C</td>
</tr>
<tr>
<td>Heat recovered from heat storage during first year</td>
<td>44%</td>
<td>18%</td>
<td>78%</td>
<td>55%</td>
</tr>
<tr>
<td>Heat recovered from heat storage during second year</td>
<td>38%</td>
<td>65%</td>
<td>90%</td>
<td>44%</td>
</tr>
<tr>
<td>Heat recovered from heat storage during third year</td>
<td>102%</td>
<td>62%</td>
<td>91%</td>
<td></td>
</tr>
<tr>
<td>Heat recovered from heat storage during fourth year</td>
<td>46%</td>
<td>67%</td>
<td>96%?</td>
<td></td>
</tr>
<tr>
<td>Heat recovered from heat storage during fifth year</td>
<td>Not used</td>
<td>38%?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Water pits - challenges:

- Floating lid
- Removal of rain water
- Water quality/life time
- Liner/life time
- Construction
- Inlet arrangement
- Optimal operation
Individual solar/electric heating systems with heat storages, which can be heated by solar collectors and by electricity in periods with low electricity prices

- Heat is produced by solar collectors and by electric heating elements or a heat pump
- Electric heating elements/heat pump if possible only in operation in periods where solar heat can not fully cover heat demand and where the electricity price is low
- System equipped with a heat storage and a smart controller operated by the energy system operator. The control based on:
  - heat content in heat storage and house
  - prognoses for heat demand
  - prognoses for solar heat production
  - prognoses for electricity production
  - prognoses for electricity consumption
  - prognoses for electricity price
Ongoing research project with Suntherm ApS, TI and DTU Byg with the aim to develop and demonstrate a smart heating system based on heat pump, heat storage and smart control for the future energy system.
SUNTHERM heating system

1. Heat pump
2. Heat storage
3. Central heating unit
4. Smart control

SUNTHERM heat of fusion storage:
70 cm cylinder design
Content: 350 kg salt hydrate
Heat content: 25 kWh
SUNTHERM control

SMART HEAT control:
- Control via internet or app
- Detailed overview
  ✓ Based on prognoses for electricity costs and weather forecasts
  ✓ Solar radiation and wind energy production considered
  ✓ Heat demand for house known 48 hours ahead
  ✓ Heat content of heat storage considered
  ✓ Heat bill as inexpensive as possible
Smart solar tanks with variable auxiliary volume for solar heating systems

Marketed Solar tank

Smart solar tank

- Tank heated from the top
- Controller based on heat content and prognoses for heat demand, electricity production and consumption

Increased thermal performance by up to 35% due to:
😊 Decreased tank heat loss
😊 Increased solar heat production

Further, also additional improved cost efficiency due to:
😊 Use of low electricity price
Systems tested side by side

- 9 m² solar collector
- 735 l smart solar tank. Auxiliary: One electric heating element, three electric heating elements, heat pump
- Smart control system - heat content in tank, weather forecast, coming heat demand, coming solar heat production, coming electricity prices from NORDPOOLSPOT
Measured results for spring 2013

- Electricity consumption of system with electric heating element(s) = 2.2 x electricity consumption of system with heat pump

- Heat price for systems with electric heating element(s) = 2 x Heat price for system with heat pump

Theoretical calculations - results

Strongly influenced by policy on energy taxation

Home owner
- Heat price for house: 100%
- Heat price for house with 10 m² solar combi system: 75%
- Heat price for house with 10 m² smart solar heating system with electric heating elements and variable electricity price: 70%
- Heat price for house with 10 m² smart solar heating system with heat pump and variable electricity price: 35%

Society
- Socio-economic benefit of smart solar heating systems compared with a reference scenario with fossil fuels
- Excellent interplay with energy system by use of smart controller operated by the grid responsible
Conclusions

Centralised solar heating systems with smart long term heat stores
• Water pit and borehole storages promising technologies for solar heating plants

Individual solar heating systems with smart solar heat stores
• Individual smart solar heating systems with electric heating elements/heat pump and variable electricity price are more cost-effective than traditional solar heating systems

Solar heating systems with smart solar heat stores with electric heating elements/heat pump can help integrating wind power in the energy system and contribute to an increased share of renewable energy

Solar heating systems with smart solar heat stores will be an important part of the future smart energy system

Recommendations

Increase research, development and demonstration efforts on:
• Water pits
• Borehole storages
• Individual smart solar/electric heating systems for low energy buildings
• Individual smart solar/heat pump systems for normal houses