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

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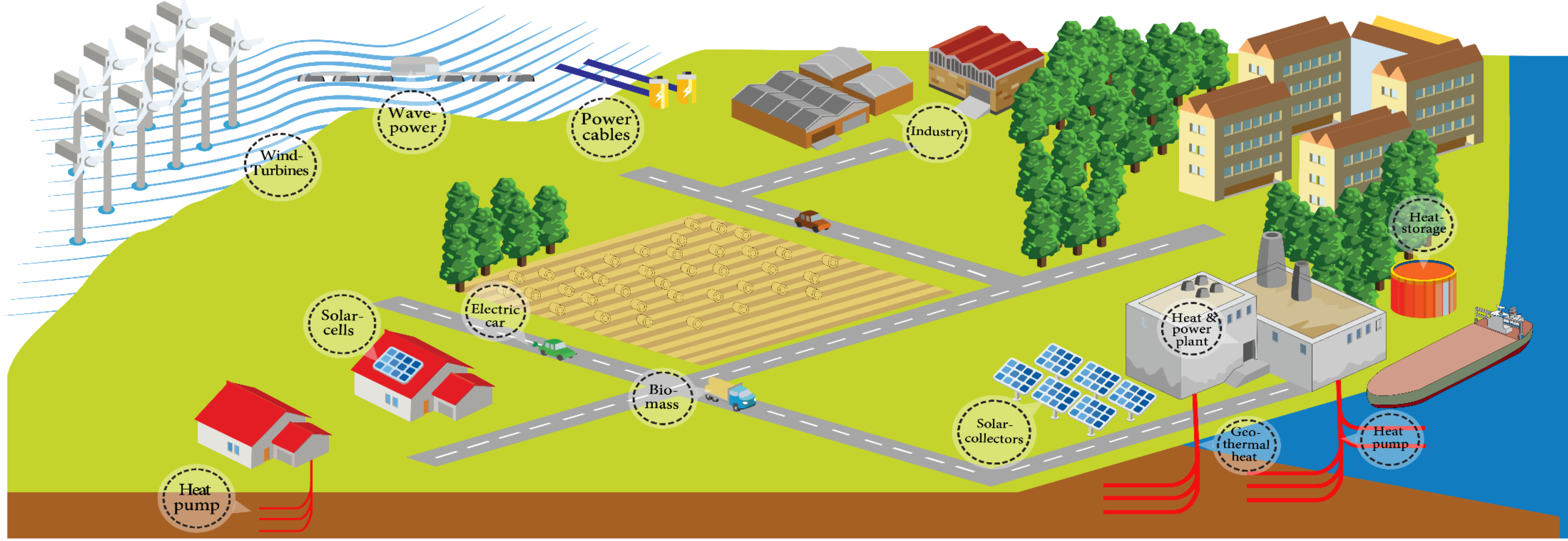


Denmark 2050: Independent of fossil fuels

<u>Wind energy:</u>
2017, 43% of electricity consumption
2020: 50 % of <u>increased</u> electricity consumption (incl. transport, heat pumps, …)
<u>Solar heating:</u>
2030: 15% of <u>decreased</u> heating demand
2050: 40% of <u>decreased</u> heating demand - 80% of this by solar heating plants & 20% individual systems

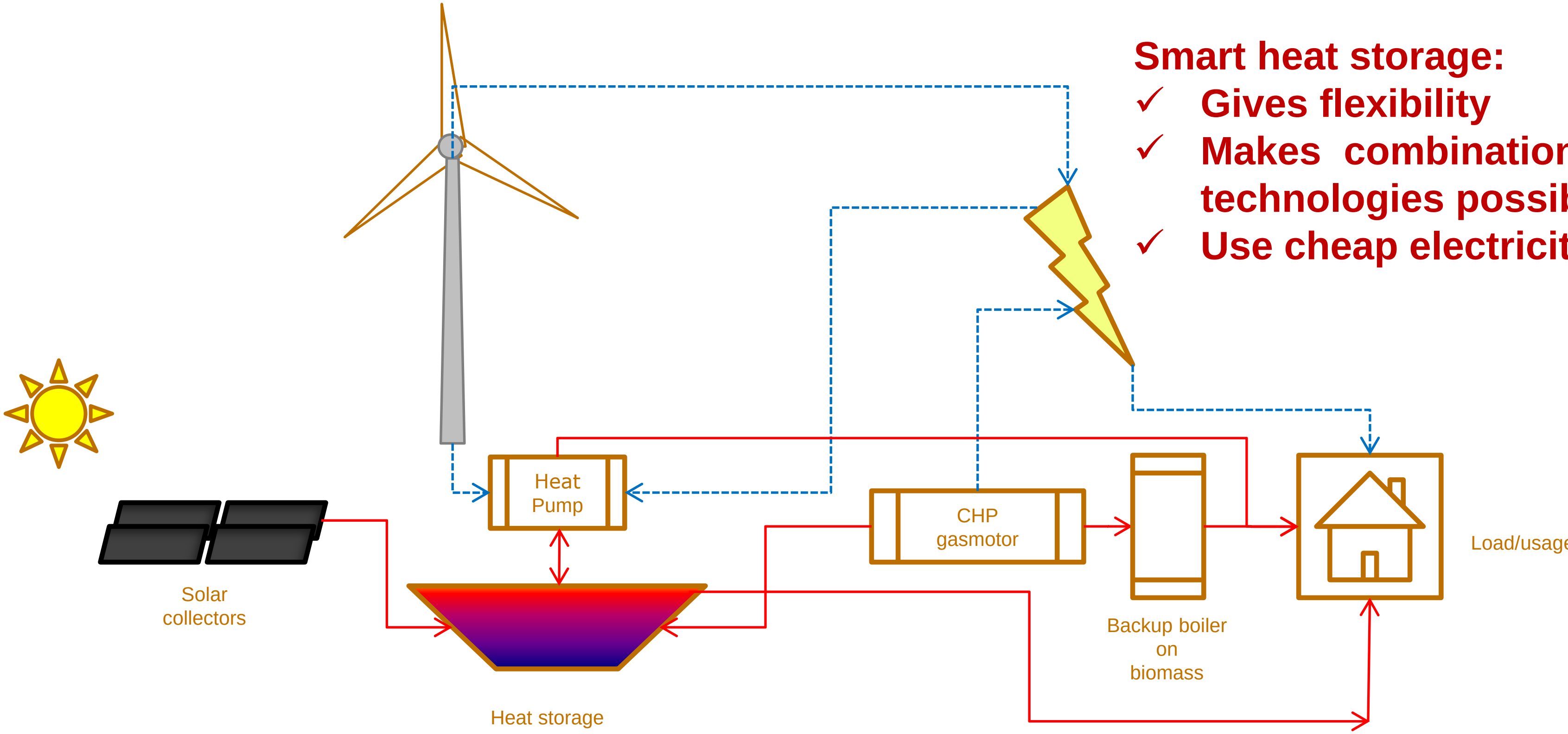
How will solar heating systems achieve a good interplay with the energy system?

Solution:

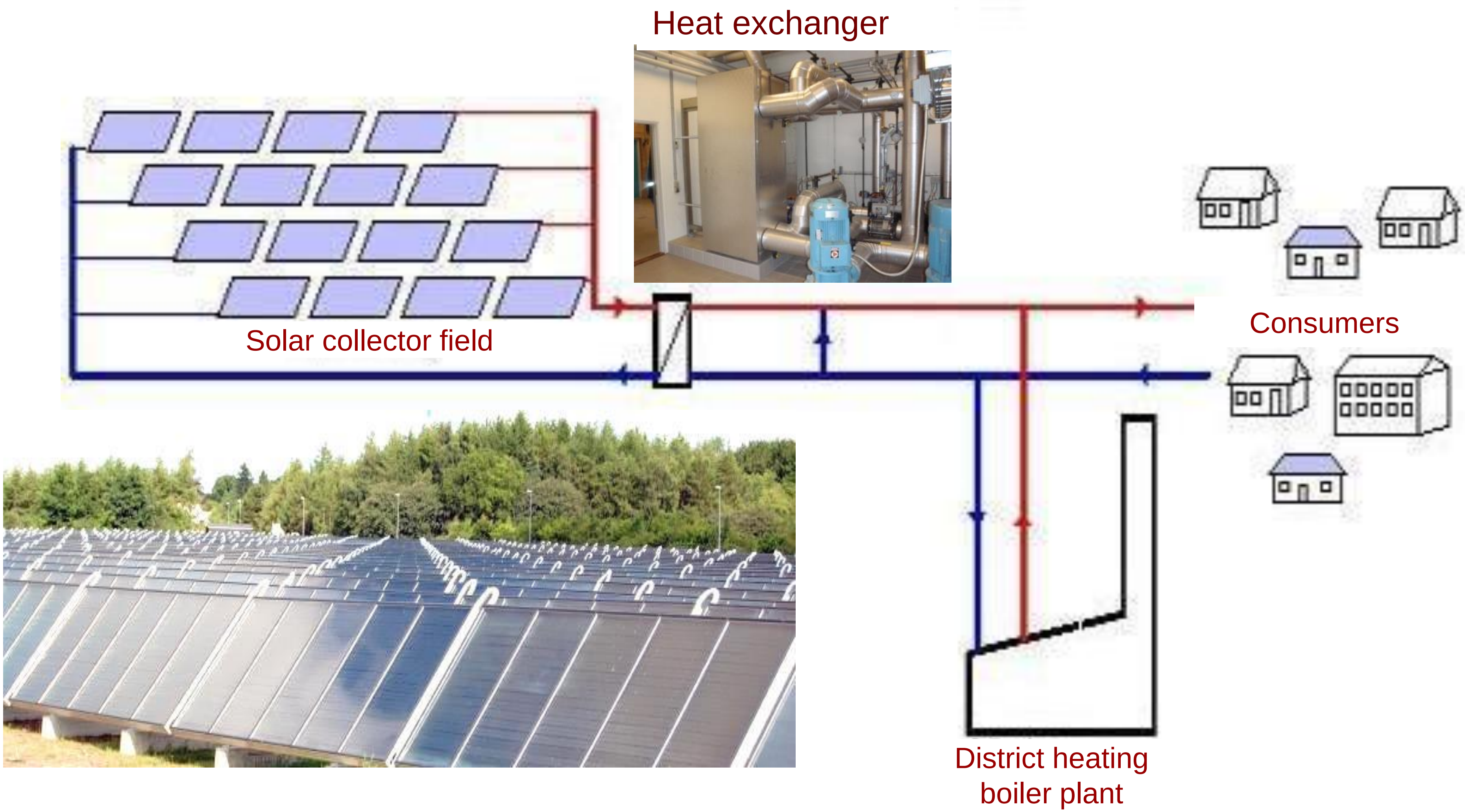
Combined technologies and smart heat storage interacting with the electricity grid …

Smart heat storage:

- ✓ Gives flexibility
- ✓ Makes combinations of technologies possible
- ✓ Use cheap electricity

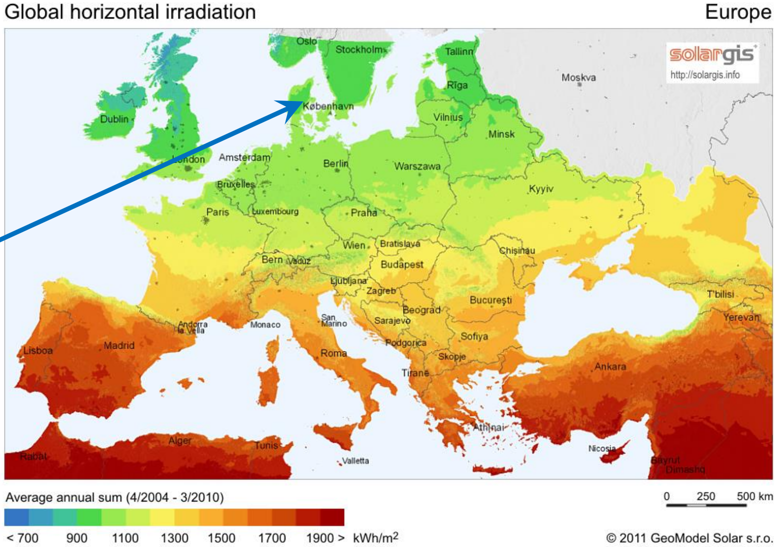


Solar heating plant - principle



Solar heating plants

Solar heating plants by end of 2016



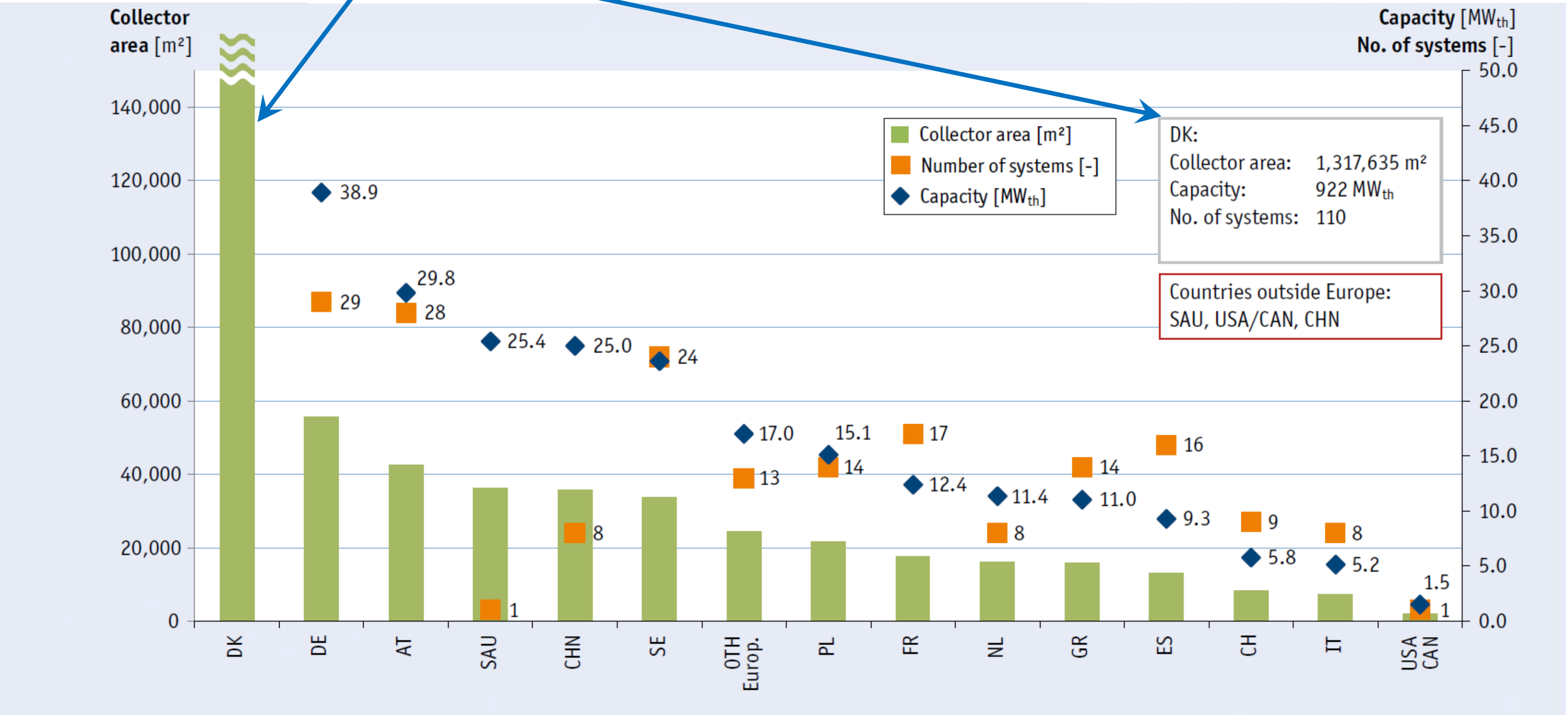
300 solar heating plants > 500 m²

110 in Denmark, 37%

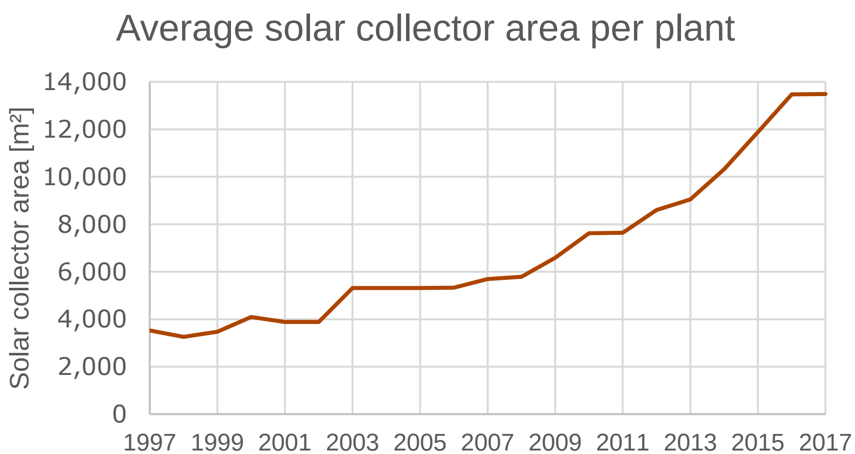
1,648,383 m² in operation

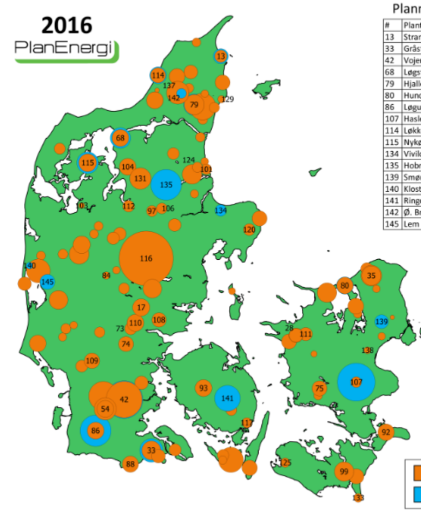
1,317,635 m² in Denmark, 80%!

Denmark



Solar heating plants in Denmark





Planned new & expansions

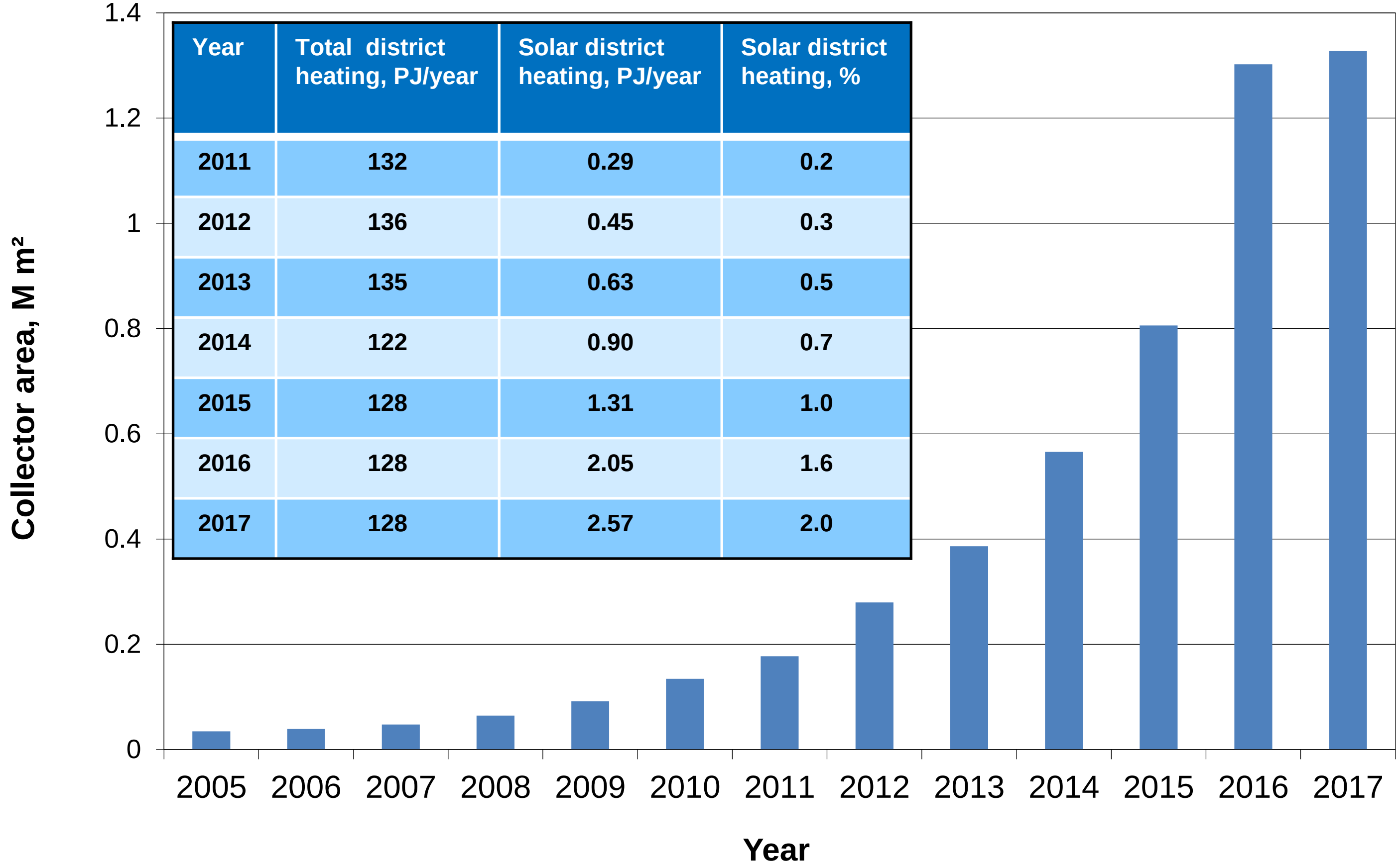
#	Plant	Collector area (m2)
13	Strandby	(8019)+4000
33	Gråsten	(19024)+11189
42	Vojens	(17500+52492)+5000
68	Løgstør	(15208)+7000
79	Hjallerup	(21546)+2500
80	Hundested	(14465)+1200
86	Løgumkloster	(9699+5576)+36000
107	Haslev	(6010)+70000
114	Løkken	(12096)+3000
115	Nykøbing Mors	(16708)+8000
134	Vivild	7000
135	Hobro	50000
139	Smørum	10000
140	Kloster	2300
141	Ringe	35000
142	Ø. Brønderslev	5000
145	Lem	12000

New plants & expansions in operation

#	Plant	Collector area (m2)
17	Tørring	(7284)+8467
28	Svebølle-Visking.	(7035+3000)+1000
35	Helsinge	(4733+14855)+3276
54	Toftlund	(11000)+15000
73	Bredsten - Balle	7800
74	Egtved	12000
75	Fuglebjerg	12000
84	Kølkær	2873
86	Løgumkloster	(9699)+5576
88	Padborg	13961
92	Stege	14515
93	Tommerup	15000
97	Ørum	6375
99	Øster Toreby	20000
101	Als (Mariagerfj.)	5947
103	Ejsing	1800
104	Farsø	15120
106	Hammershøj	6000
107	Haslev	6010
108	Hedensted	11000
109	Holsted	12500
110	Jelling	15290
111	Jyderup	9239
112	Løgstrup	7031
114	Løkken	12096
115	Nykøbing Mors	16708
116	Silkeborg	156694
117	Skårup (Sydfyn)	5418
120	Trustrup-Lyngby	7245
124	Veddum (VSV)	5500
125	Søllested	4701
129	Voerså	2873
131	Aalestrup	24129
133	Gedser	4000
137	Brønderslev	26929
138	Havdrup	2569

In operation
Planned / planned expansion

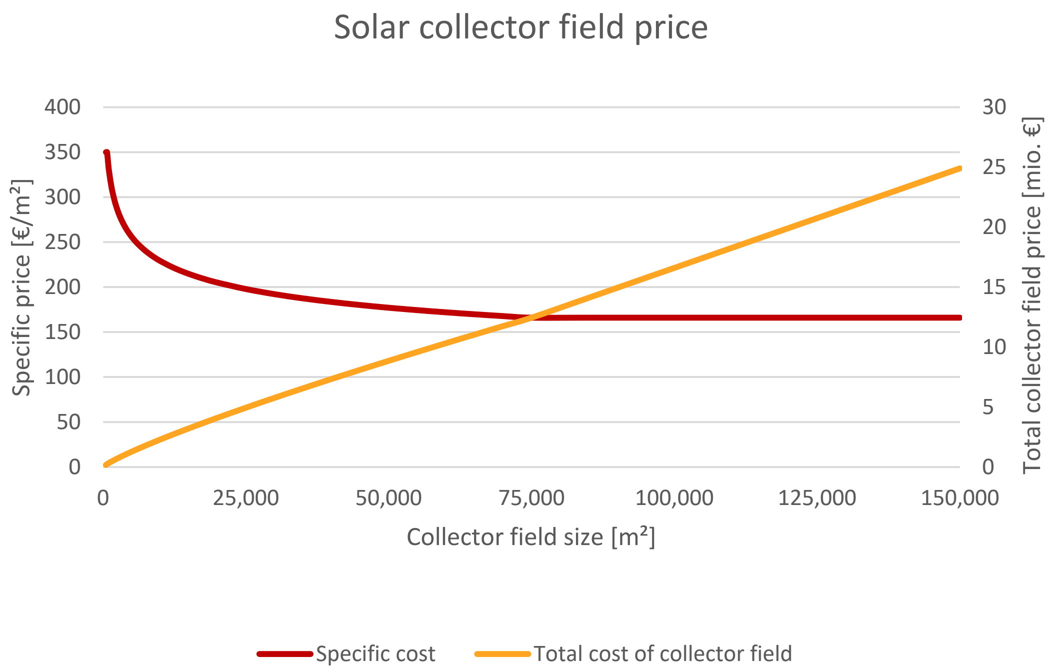
Total collector area (in operation): 1 302 331 m^2
Total collector area (planned): 269 189 m^2

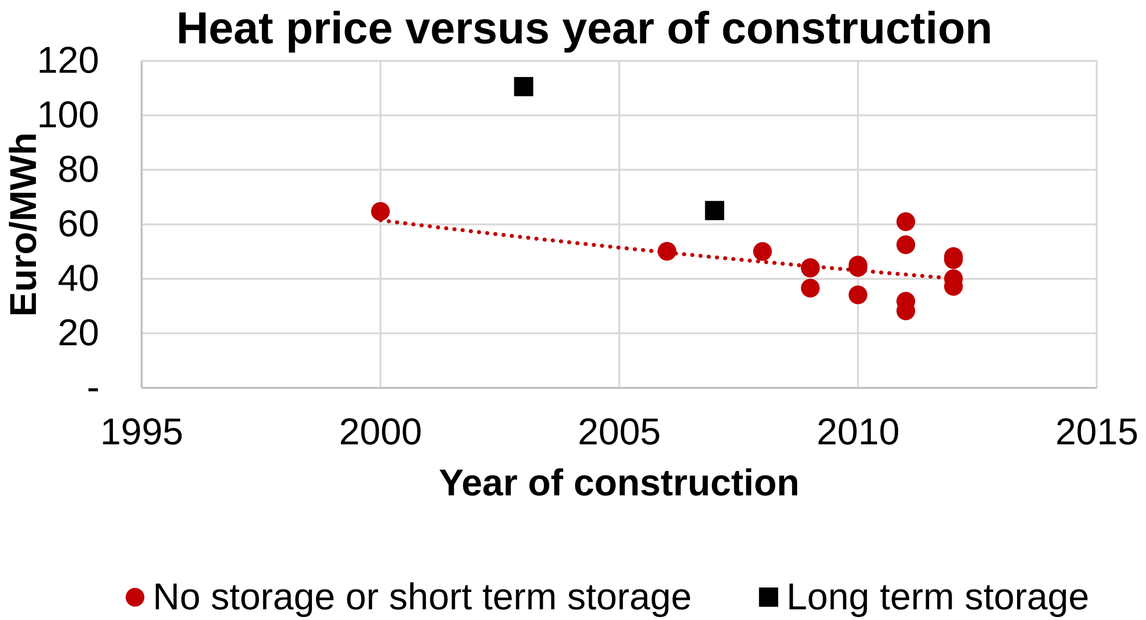


Year	Total district heating, PJ/year	Solar district heating, PJ/year	Solar district heating, %
2011	132	0.29	0.2
2012	136	0.45	0.3
2013	135	0.63	0.5
2014	122	0.90	0.7
2015	128	1.31	1.0
2016	128	2.05	1.6
2017	128	2.57	2.0

Planned plants: 371.513 m²

Investment cost per m² collector



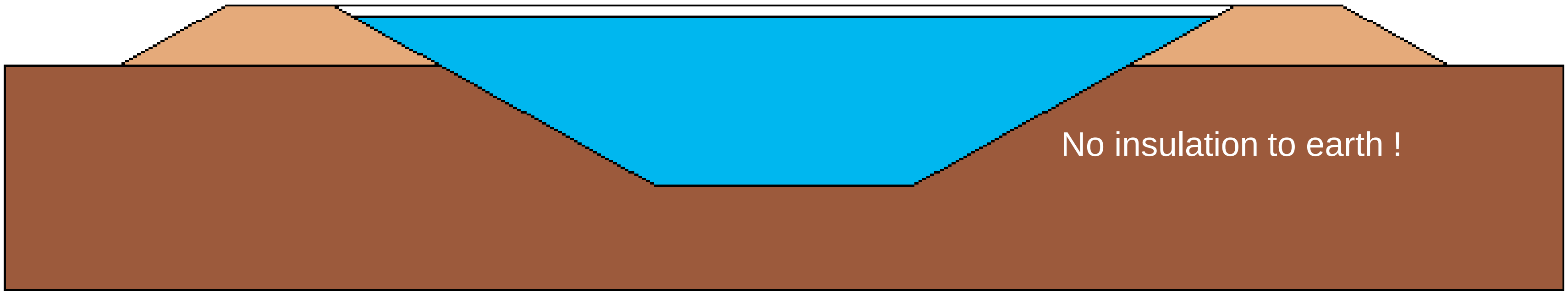


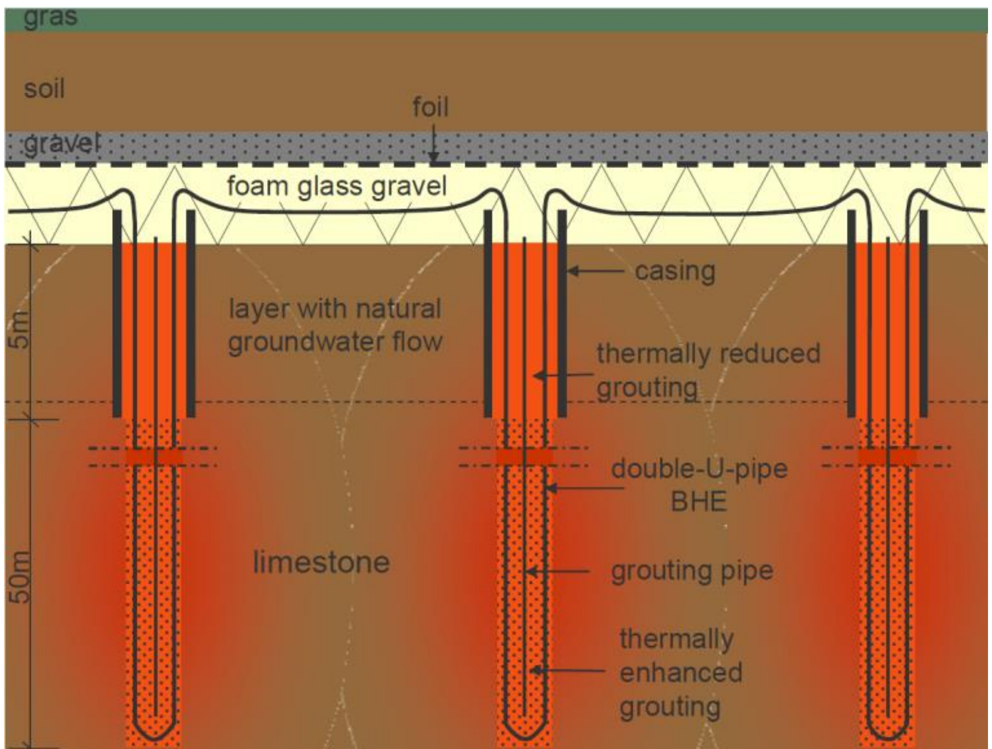
Solar heating plants' interaction with variable electricity production improved and cost efficiency hardly influenced by:

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 m^3

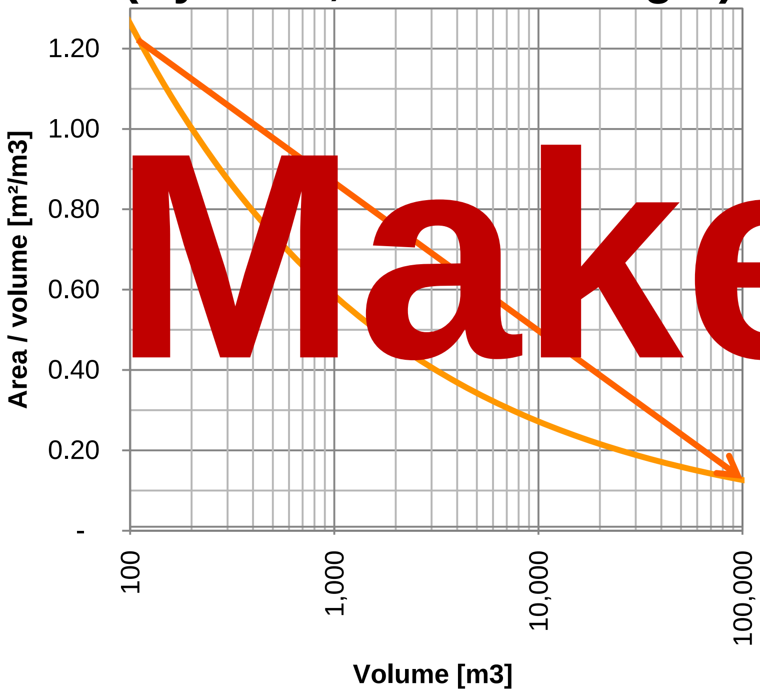

Vojens 200,000 m^3


Dronninglund 62,000 m^3

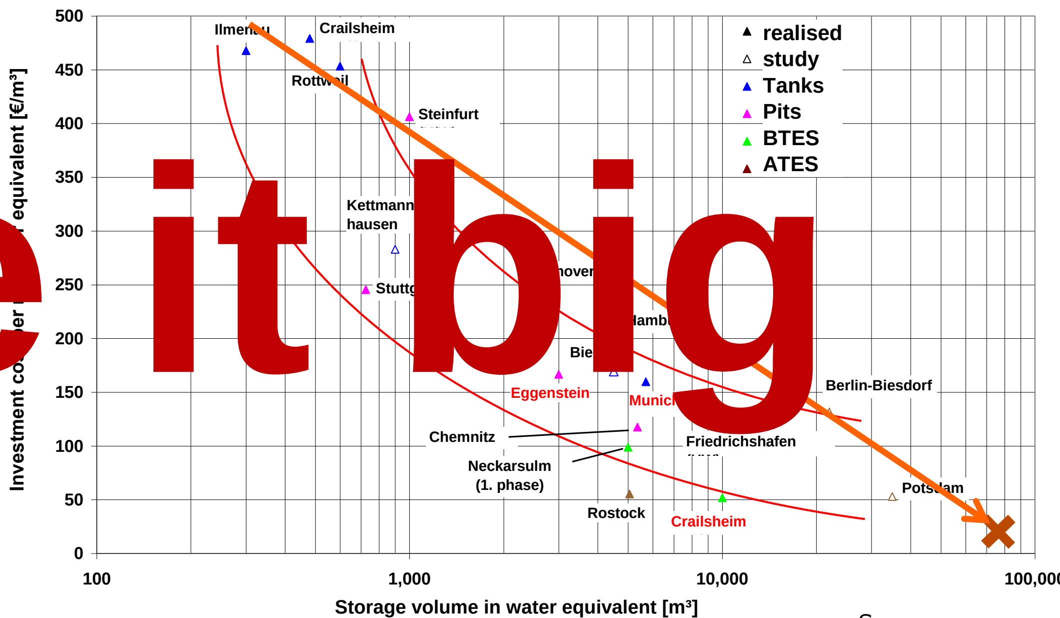

Gram 110,000 m^3

LARGE SYSTEMS → small storage losses & lower specific costs

Surface area per volume (Cylinder, Radius = Height)



Cost per equivalent m³



Make it big

Source: SOLITES

1.2 → 0.1 ➔ Factor 12!

500 → 20 ➔ Factor 25!

Water pits for seasonal heat storage with water volumes > 60,000 m³: Yearly heat loss < 10%

Measurements

	Borehole storage, Brædstrup	Water pit storage, Marstal	Water pit storage, Dronninglund	Water pit storage, Gram
Size	19000 m^3 soil, corresponding to about 12000 m^3 water	75000 m^3 water	62000 m^3 water	110000 m^3 water
Maximum storage temperature	50°C	90°C	90°C	90°C
Heat recovered from heat storage during first year	44%	18%	78%	55%
Heat recovered from heat storage during second year	38%	65%	90%	44%
Heat recovered from heat storage during third year	102%	62%	91%	
Heat recovered from heat storage during fourth year	46%	67%	96%?	
Heat recovered from heat storage during fifth year	Not used	38%?		

Water pits - challenges:

- Floating lid
- Removal of rain water
- Water quality/life time
- Liner/life time
- Construction
- Inlet arrangement
- Optimal operation

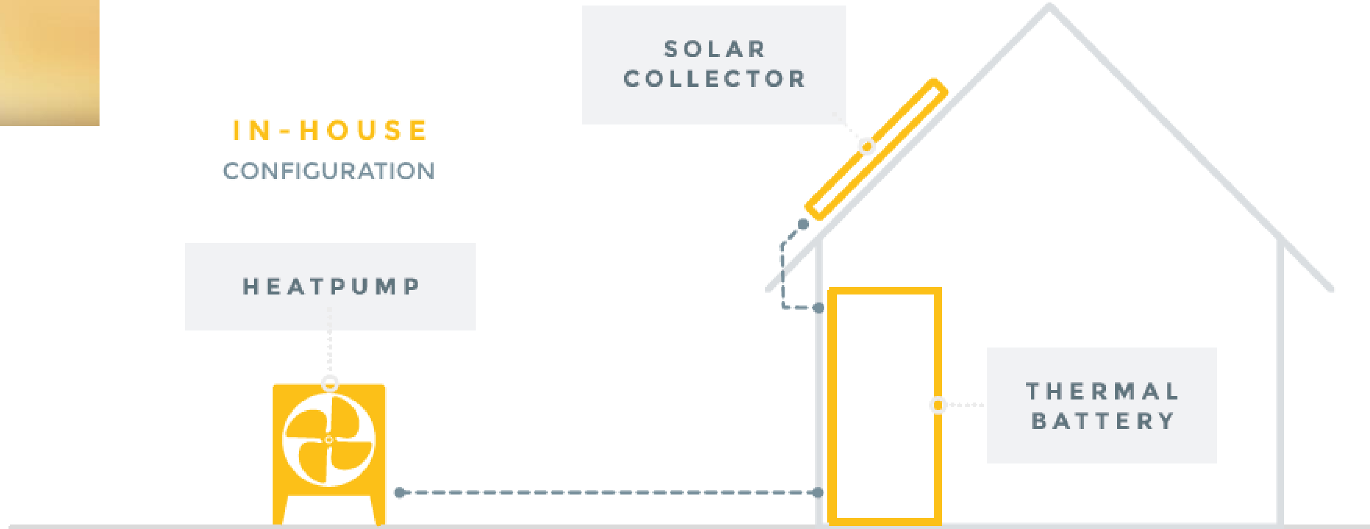
Individual solar/electric heating system for the future smart energy system

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

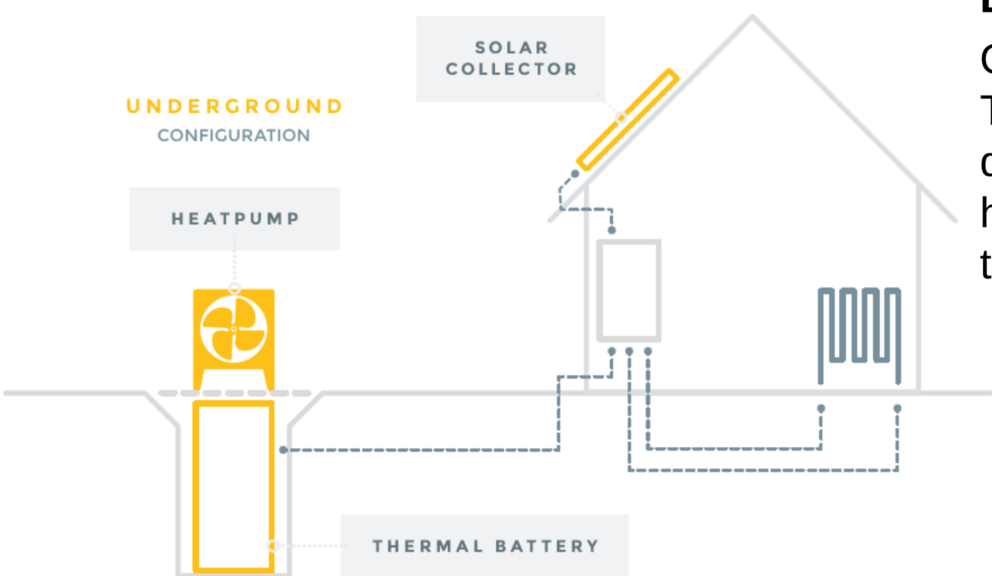
SUNTHERM

EUDP



ELEC-TO-HEAT

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

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

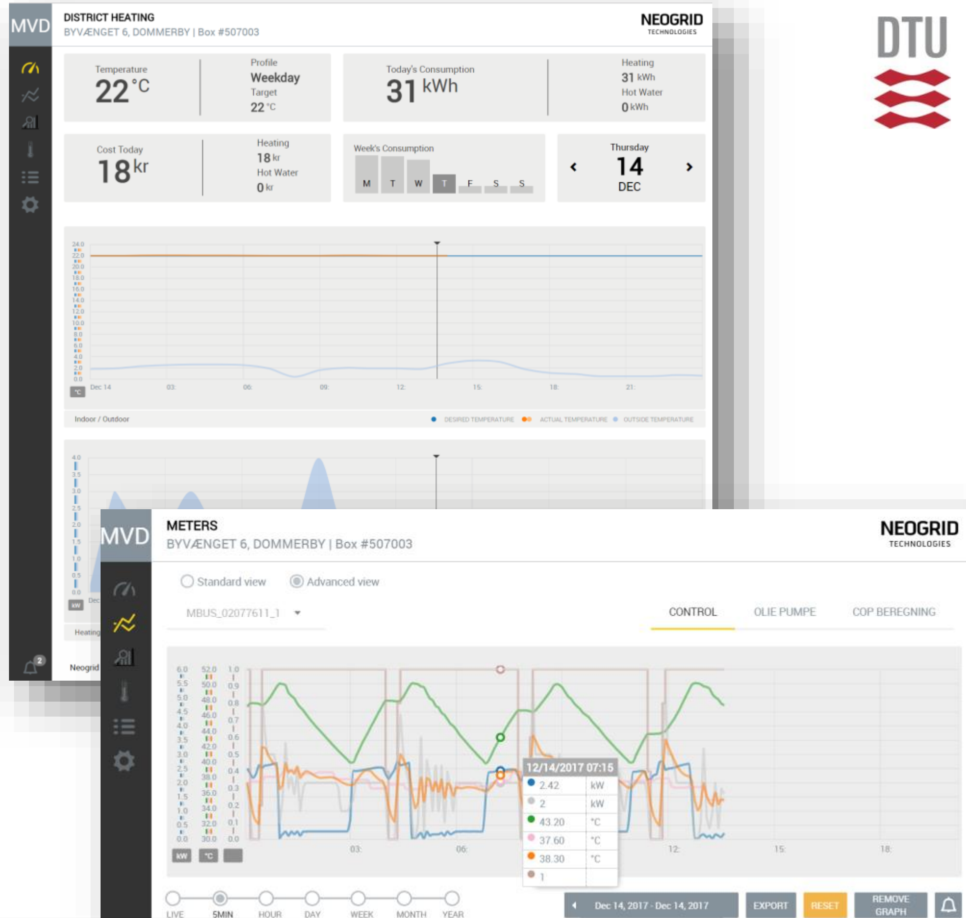
1. Heat pump
2. Heat storage
3. Central heating unit
4. Smart control

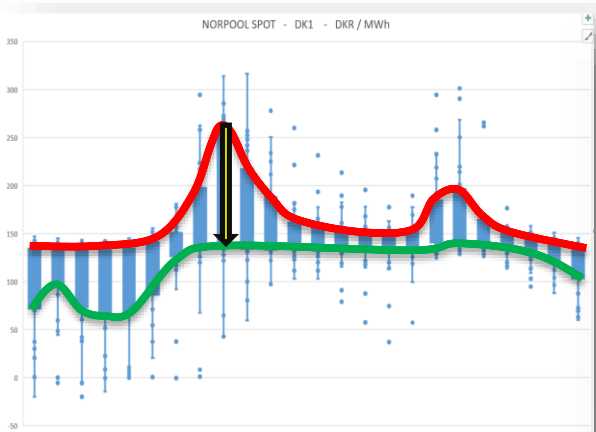


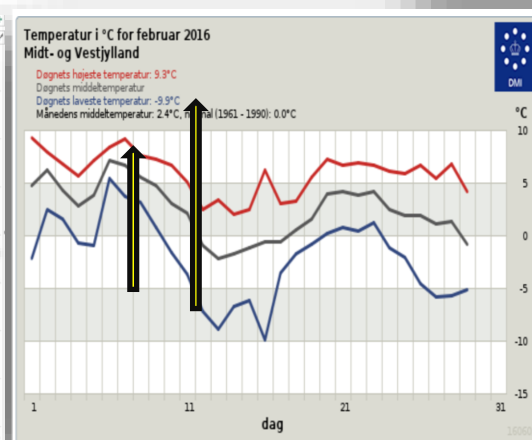

SUNTHERM control

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

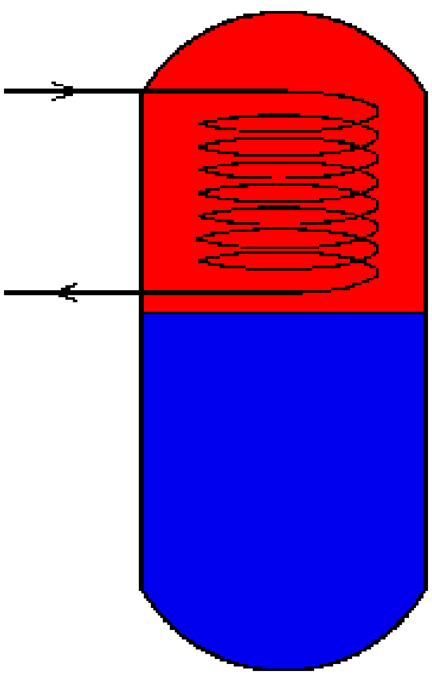




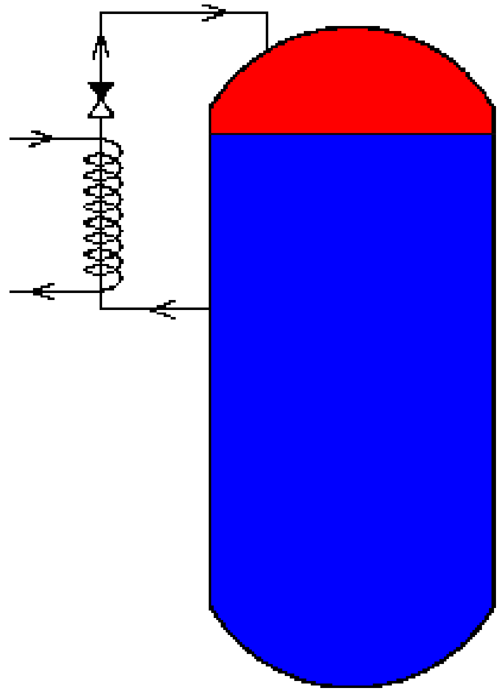


Smart solar tanks with variable auxiliary volume for solar heating systems

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