Solar heating plants and seasonal heat storage

Simon Furbo

Department of Civil Engineering

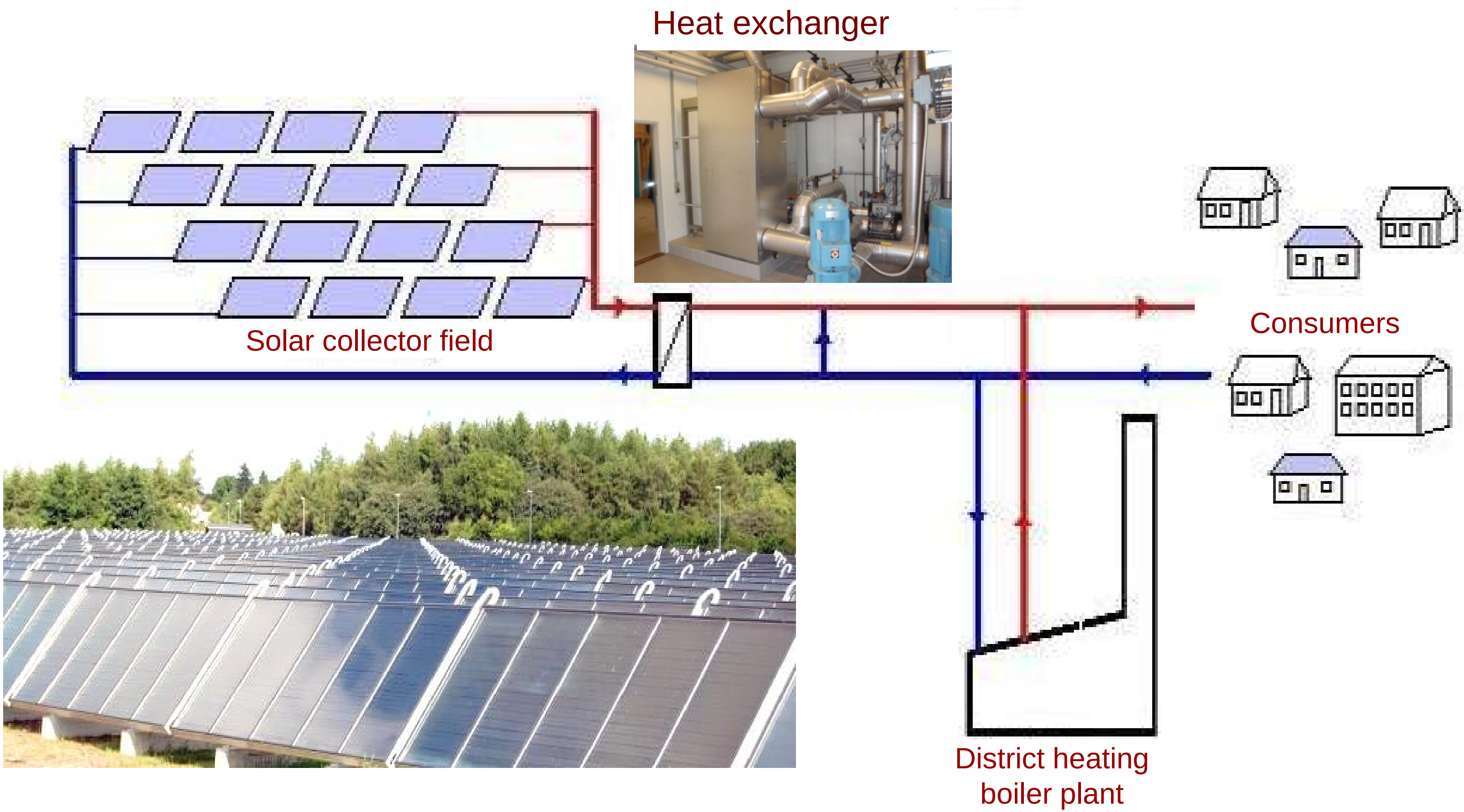
Technical University of Denmark

Building 118, Brovej

2800 Kgs. Lyngby

sf@byg.dtu.dk

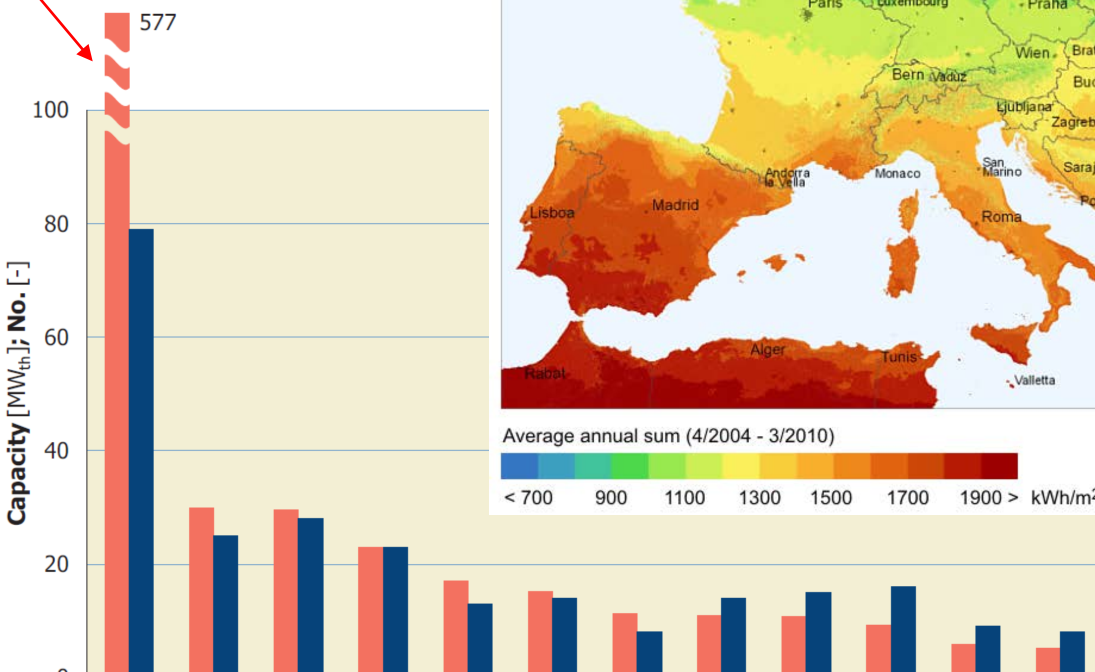
Solar heating plant - principle



Solar heating plants

Europe end of 2015:
235 solar heating plants > 500 m². 79 in Denmark, 34%
1,063,791 m² in operation. 823,838 m² in Denmark, 77%!

Denmark



	DK	DE	AT	SE	OTH	PL	NL	GR	FR	ES	CH	IT
Capacity [MW_{th}]	577	30	30	23	17	15	11	11	11	9	6	5
No. of systems [-]	79	25	28	23	13	14	8	14	15	16	9	8

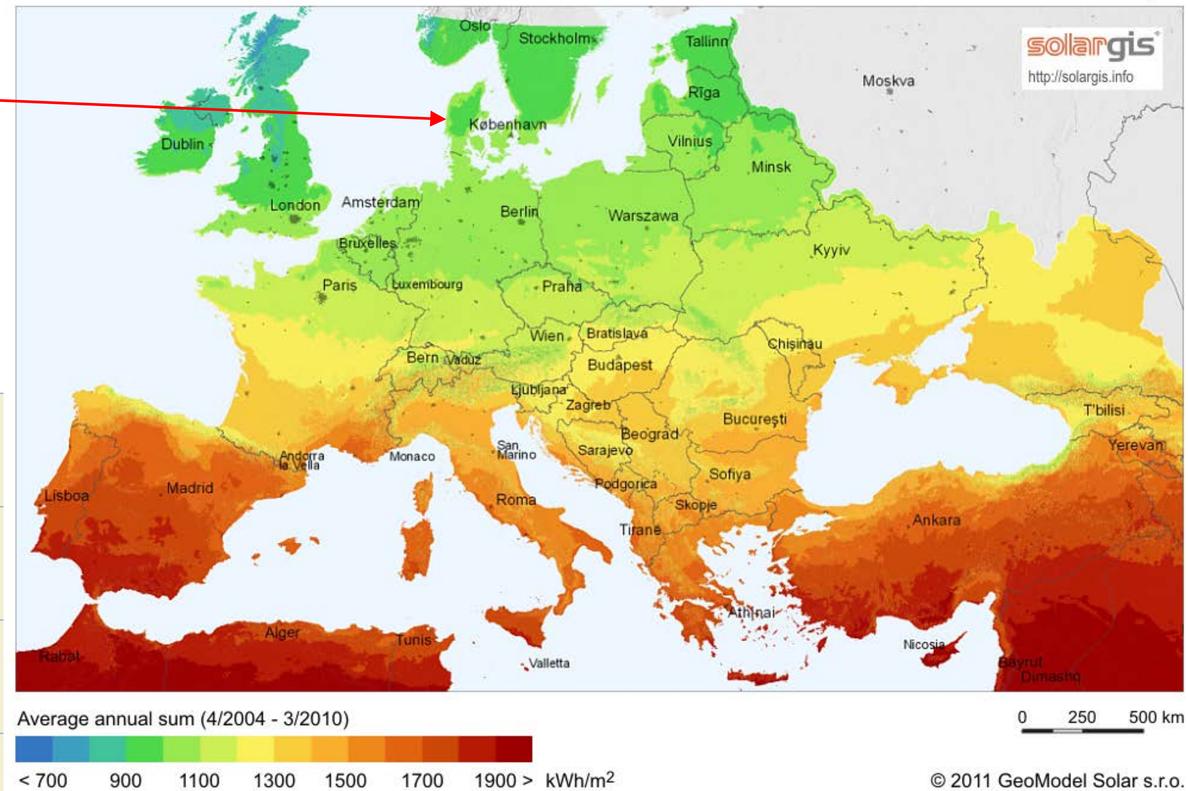
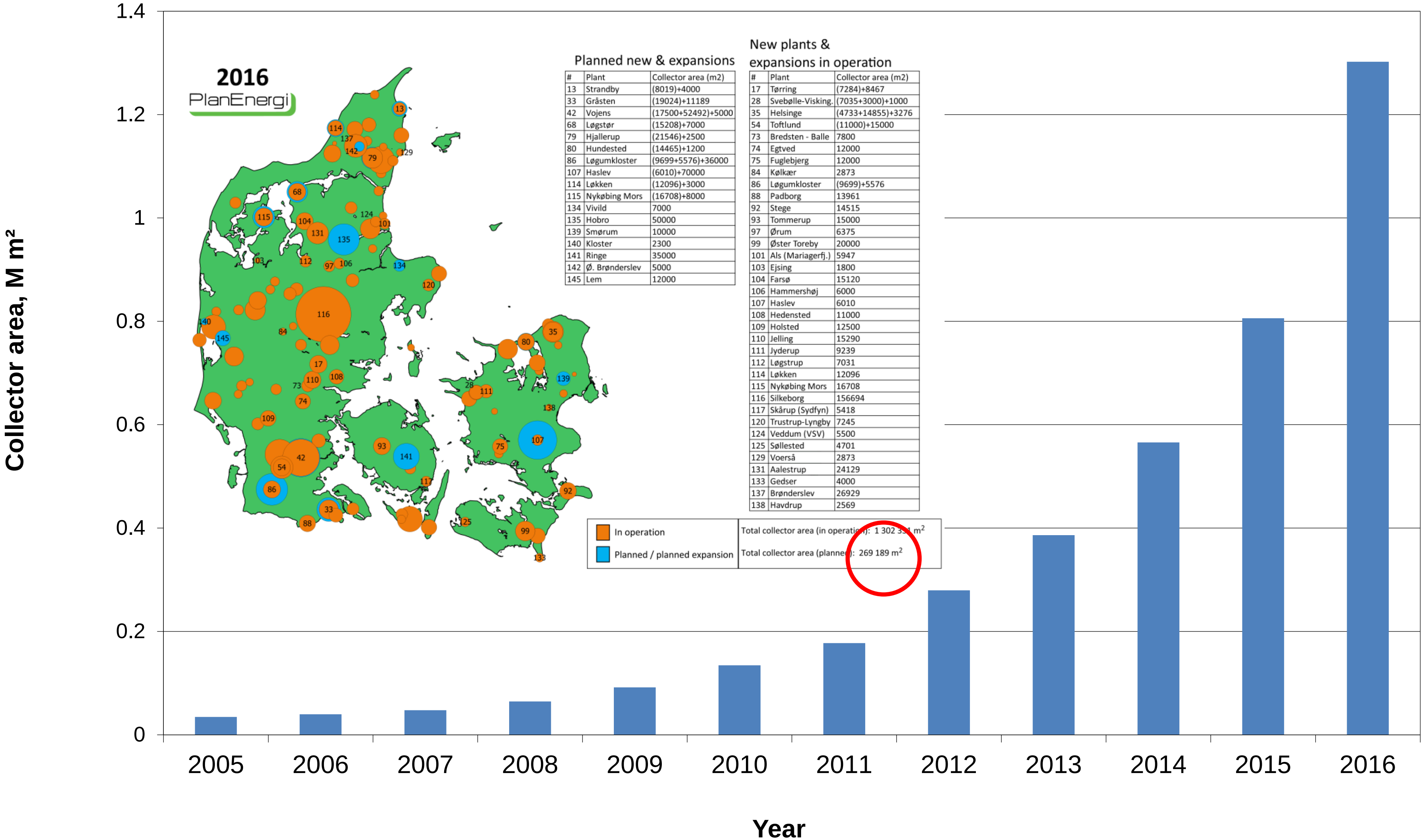


Figure 41: Solar district heating and cooling in Europe – capacities installed and No. of systems in 2015

(Data source: Jan-Olof Dalenbäck – Chalmers University of Technology, SE)

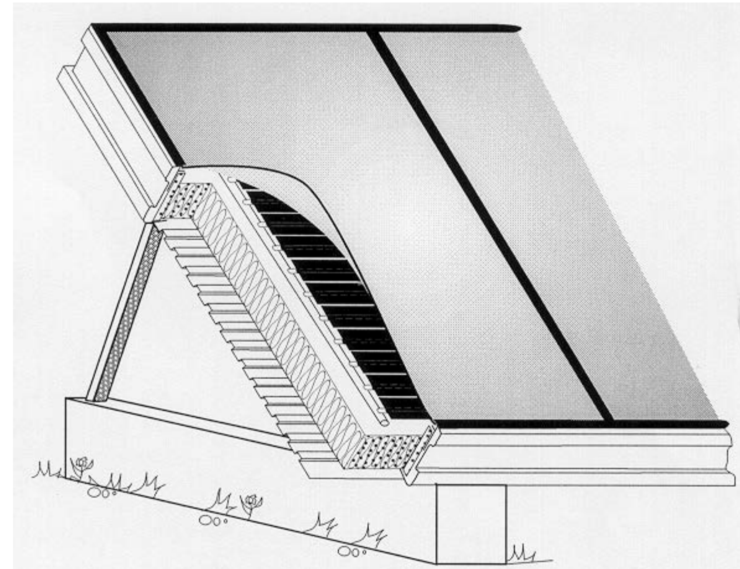
Solar heating plants in Denmark



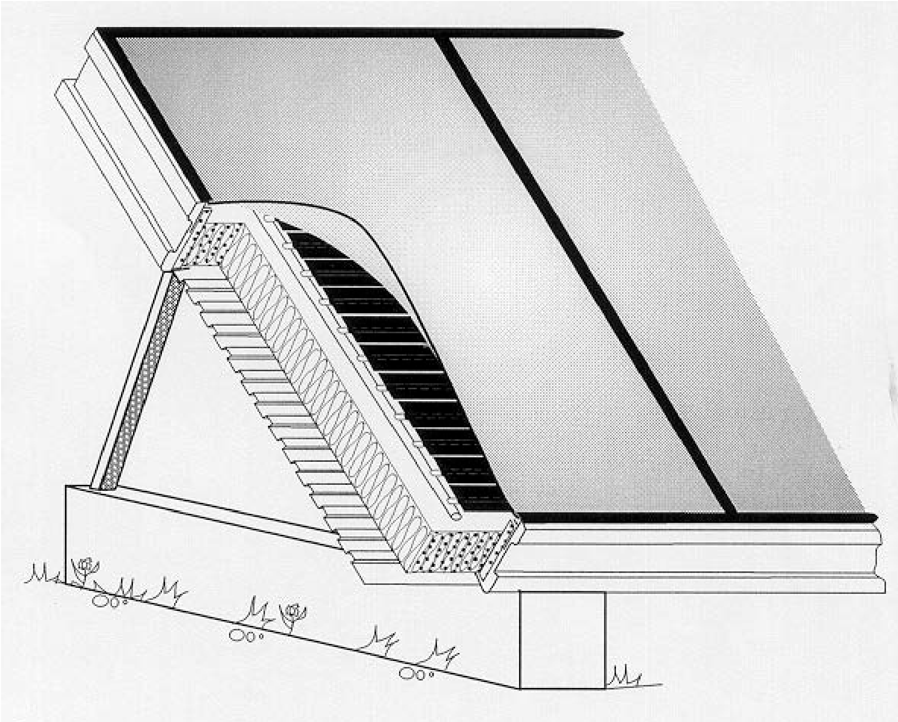
Flat plate solar collectors from Arcon-Sunmark A/S

Collectors with foil between absorber and glass

Collectors without foil between absorber and glass

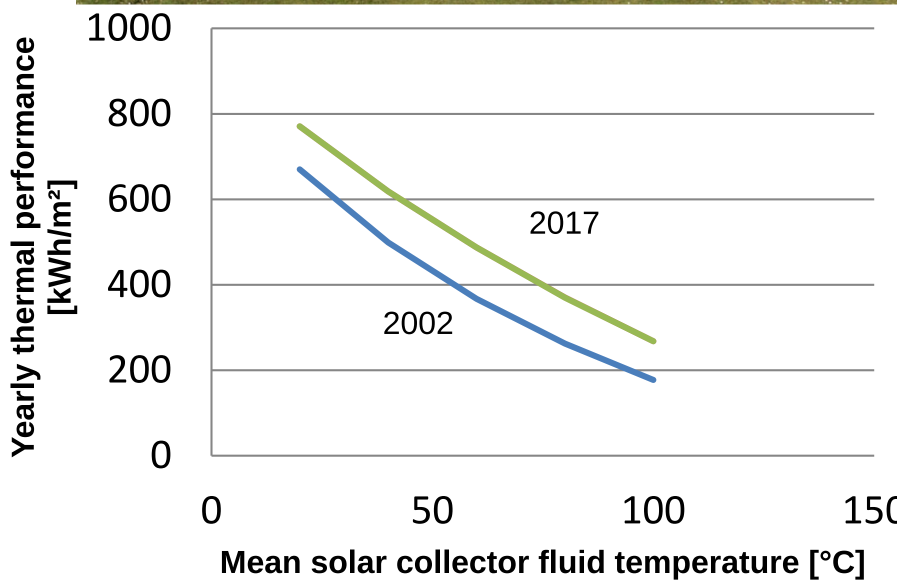


Improvement of Arcon-Sunmark A/S's HT collector with foil, 2002-2017



Changes:

- **Anti reflection treatment of glass**
- **Improved installation of foil**
- New absorber
- Improved insulation



<u>Improved thermal performance 2002-2007:</u>

40° C: 24% - **60° C: 33%** - 80° C: 41%

Measured yearly thermal performances for 48 Danish solar heating plants for 2012-2016 available from:

www.solvarmedata.dk
www.solarheatdata.eu

Collector area, m^2	Collector tilt, °	Year of installation
2970-70000	30-45	1996-2015

Measured yearly thermal performance of solar collector fields

Year	Number of solar heating plants	Yearly thermal performance, kWh/m²	Average yearly thermal performance, kWh/m²
2012	16	313-484	411
2013	21	389-493	450
2014	31	390-577	463
2015	36	322-518	439
2016	41	324-538	433

Year	Number of solar heating plants	Yearly solar radiation kWh/m²	Average yearly solar radiation kWh/m²	Yearly utilization of solar radiation %	Average yearly utilization of solar radiation %
2012	16	942-1274	1102	28-45	37
2013	21	1039-1363	1135	31-46	40
2014	31	991-1474	1114	30-51	42
2015	36	876-1325	1101	31-47	40
2016	41	975-1444	1153	30-49	38

Thermal performance influenced by:

Design of solar collector field

- Solar collector type
- Age of solar collector
- Design of pipings
- Shadows
- Heat loss from solar collector loop
- Solar collector tilt
- Solar collector orientation
- Solar collector fluid
- Moisture in solar collectors

Operation

- Solar collector fluid temperatures/operation temperatures/solar fraction
- Control strategy inclusive volume flow rate
- Flow distribution in solar collector field

Weather

- Solar radiation – direct and diffuse
- Outdoor temperature
- Wind
- Snow
- Dirt

Life time for solar collectors

Investigations:

- 13 and 15 years old solar collectors from solar heating plants investigated

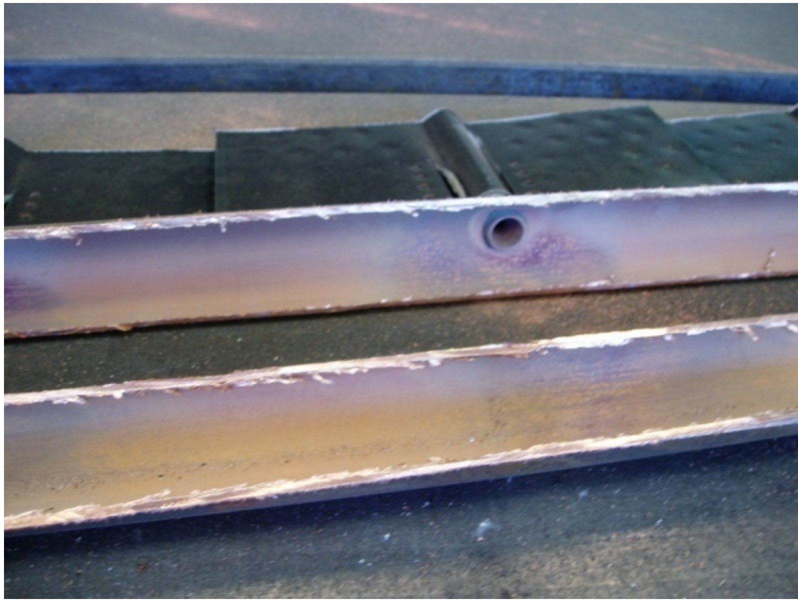
Conclusions:

- Reduced thermal performance after about 15 years of operation mainly due to wrong installation of the foil:

40° C: About 2%

60° C: About 10%

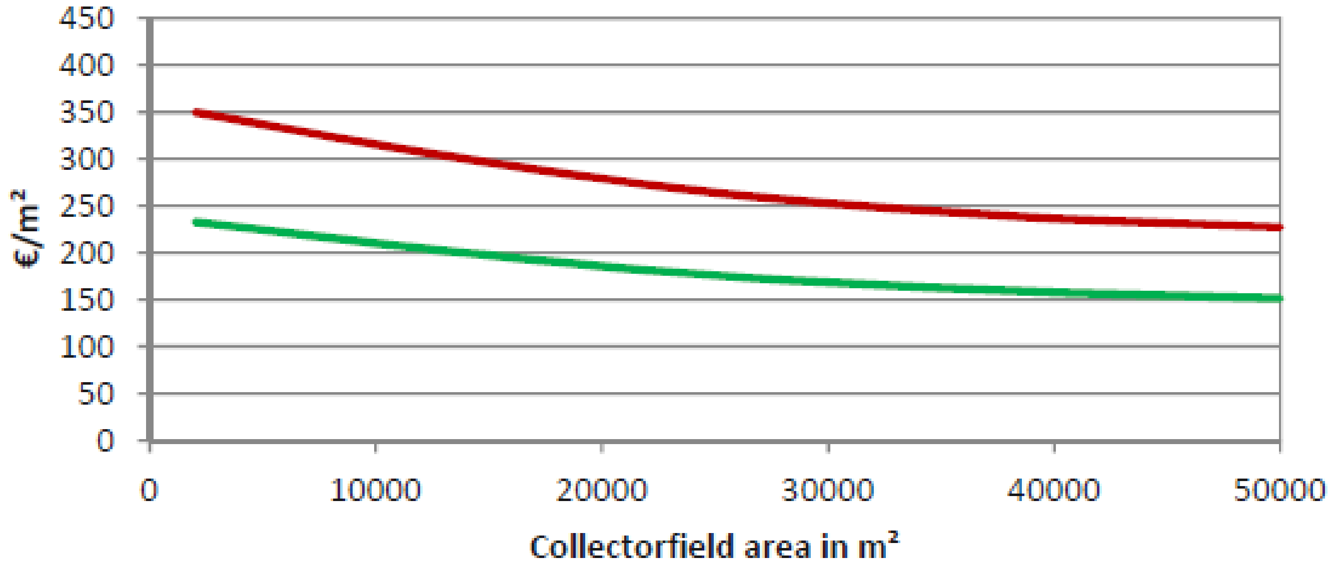
80° C: About 25%



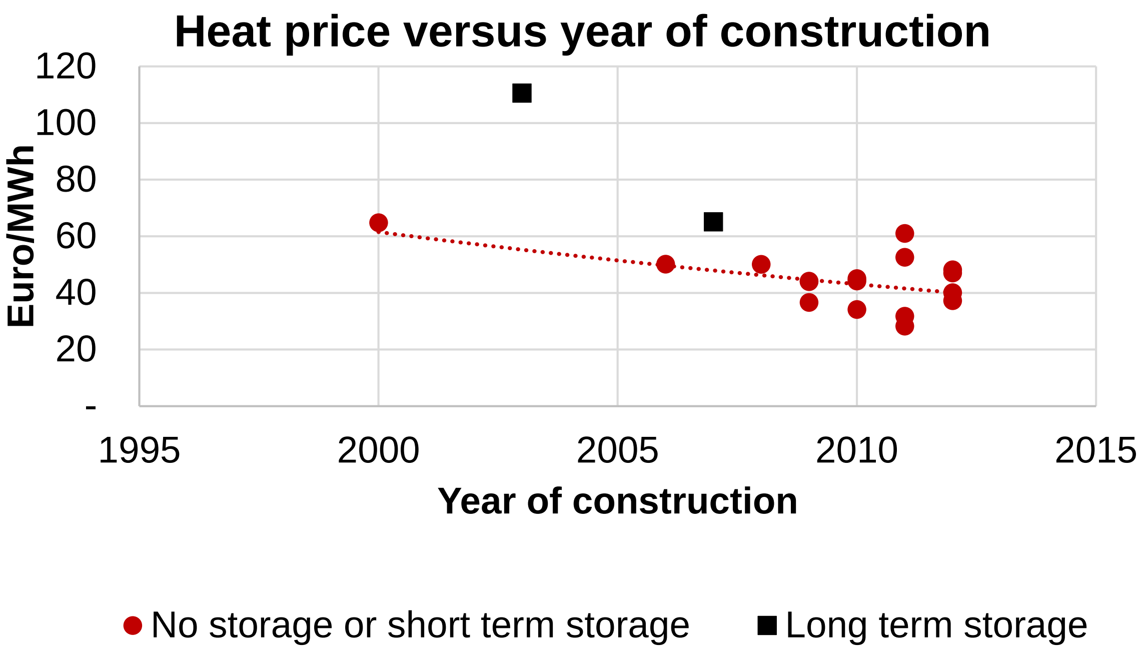
☺ **Life time of solar collectors: About 30 years**

☺ **Most likely: New collectors without foil problems**

Investment cost per m² collector

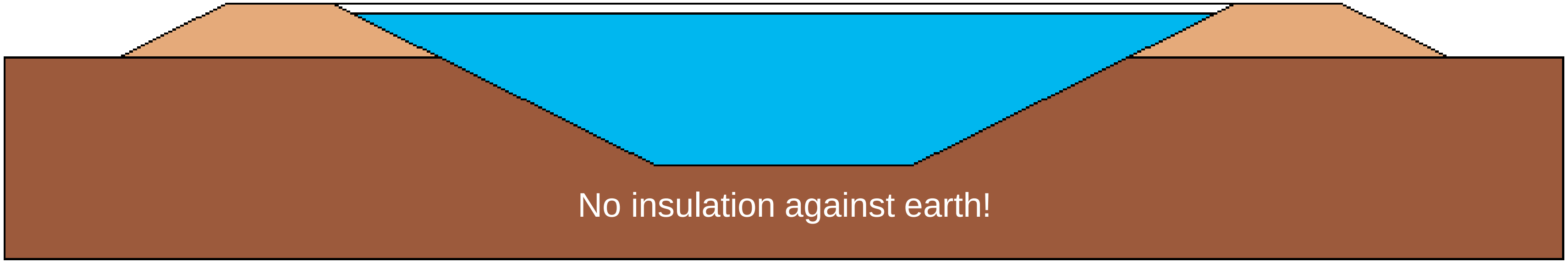


Price range per m² of ground mounted collector field, including installation, piping, HX-unit, control system (excl. storage and VAT)

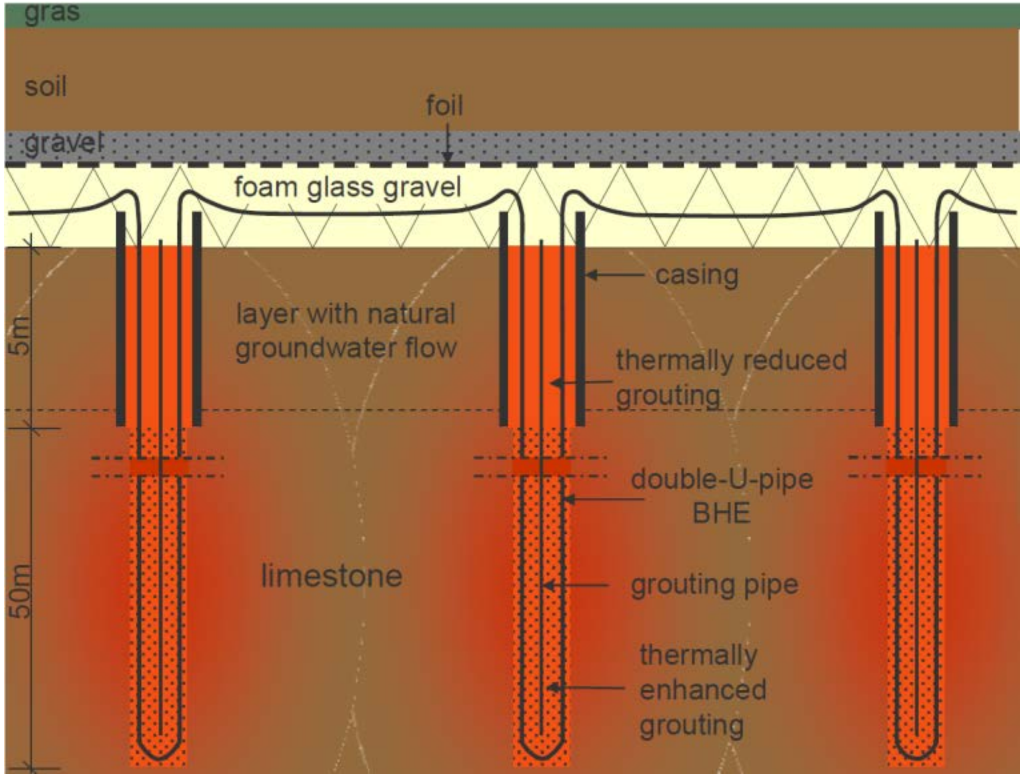


Seasonal heat storage types

Water pit

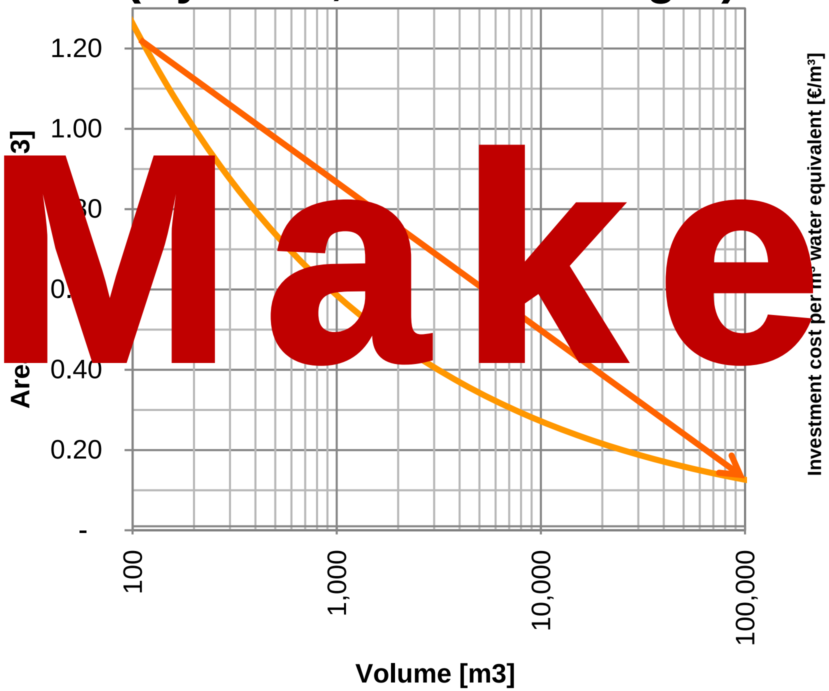


Borehole storage

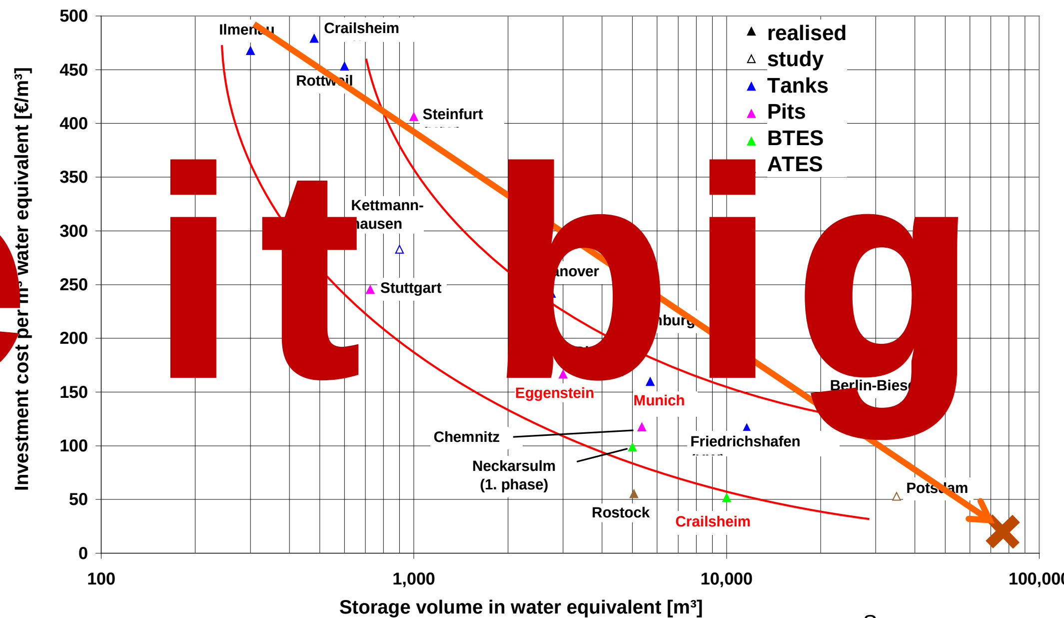


LARGE SYSTEMS → small storage losses & lower specific costs

Surface area per volume (Cylinder, Radius = Height)



Cost per equivalent m³



Make it big

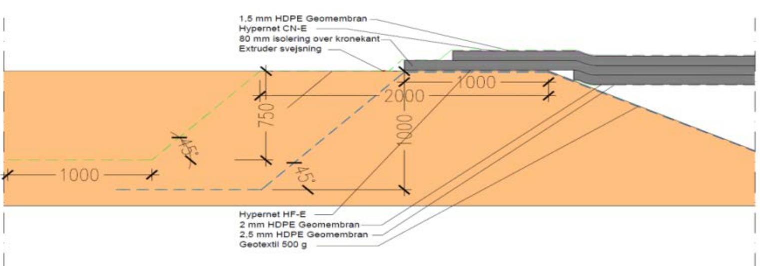
Source: SOLITES

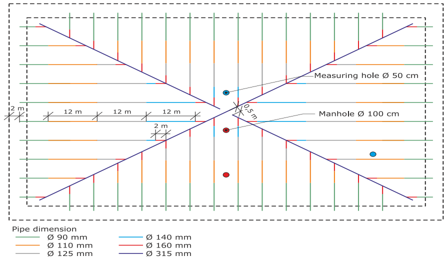
1.2 → 0.1 ➔ Factor 12!

500 → 20 ➔ Factor 25!

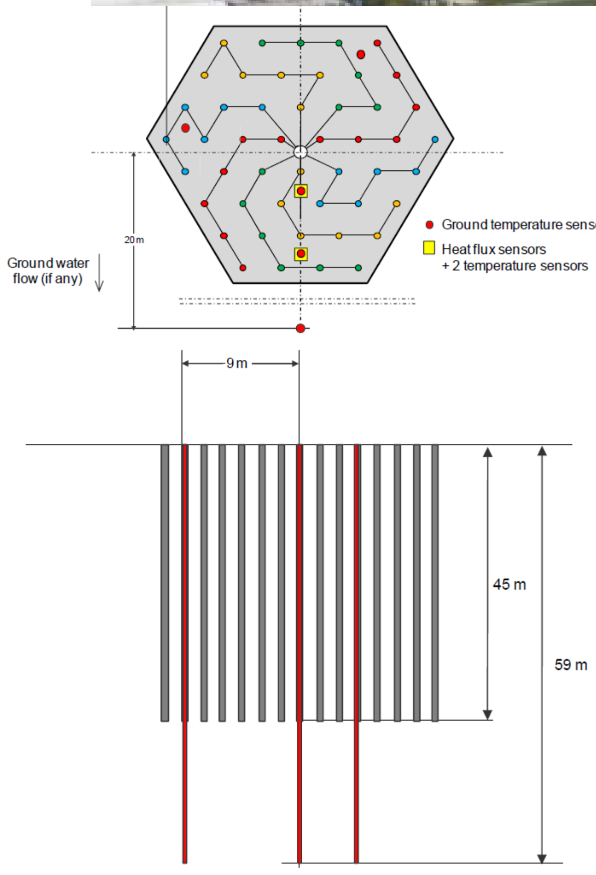
Water pits for seasonal heat storage with water volumes > 60,000 m³: Yearly heat loss < 10%

Marstal
Seasonal heat storage - 75000 m^3 water pit





19000 m^3 borehole storage in Brædstrup



Measurements

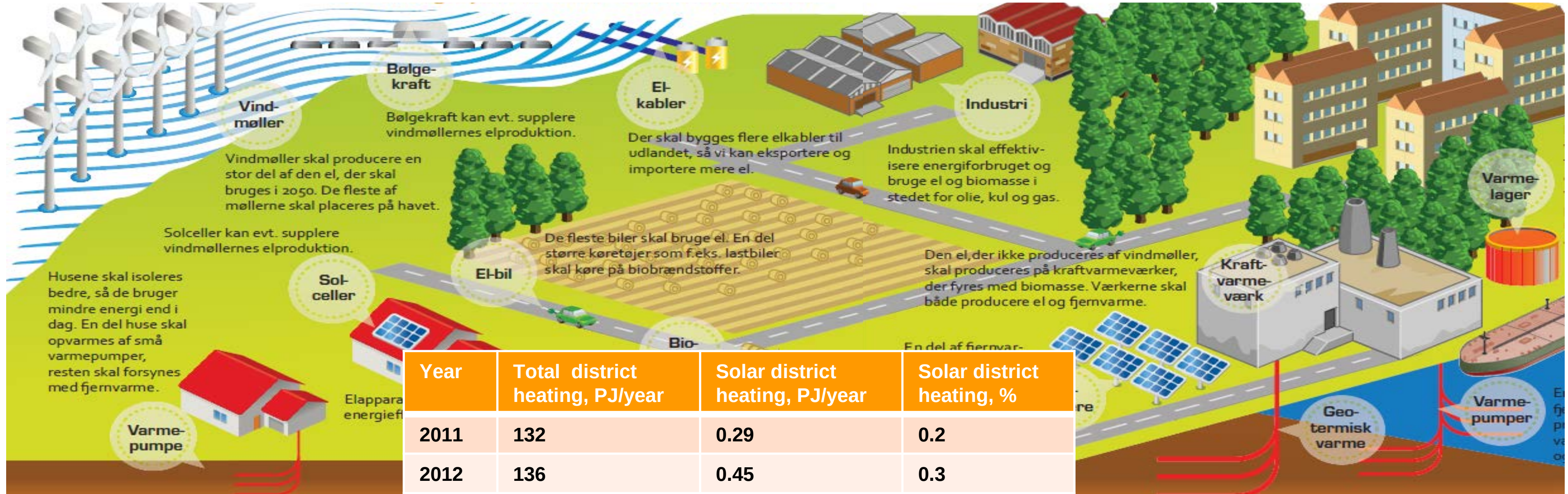
	Borehole storage, Brædstrup	Water pit storage, Marstal	Water pit storage,Dronninglund	Water pit storage, Gram
Size	19000 m^3 soil, corresponding to about 12000 m^3 water	75000 m^3 water	62000 m^3 water	110000 m^3 water
Maximum storage temperature	50°C	90°C	90°C	90°C
Heat recovered from heat storage during first year	44%	18%	78%	55%
Heat recovered from heat storage during second year	38%	65%	90%	
Heat recovered from heat storage during third year	102%	62%	91%	
Heat recovered from heat storage during fourth year	46%	Problems with measurements		

Water pits

Challenges

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

Denmark 2050: All fossil fuels phased out - 2035: All heat and electricity from renewables



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

Wind energy:
2016: 38% 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

Reasons for rapid growth of Danish solar heating plants

- Ambitious Danish energy plan. By 2035 no fossil fuels must be used for heat and electricity and by 2050 no fossil fuels must be used
- **A lot of district heating**. Today 64% of all Danish buildings are heated by district heating
- Low temperature levels in district heating systems. A typical forward temperature to towns is about 80°C and a typical return temperature from towns is about 40°C
- **High taxes for fossil fuels**. Typical tax is about 0.035 euro/kWh produced heat
- Decentralized energy supply system
- **High share of wind energy for electricity production**. In 2016, 38% of the Danish electricity consumption was produced by wind turbines. By 2020, 50% of the Danish electricity consumption must be produced by wind turbines
- **Low costs** for marketed solar collector fields installed on the ground, < 200 euro/m^2
- Relative low ground costs
- High efficiency of marketed solar collectors
- **Long life time** of marketed solar collectors, about 30 years
- Simple and well proven and reliable technology
- Good cooperation between solar heating plant owners. Regular meetings with experience exchange
- **Good thermal performance** of existing solar heating plants: About 450 kWh/m^2 year
- **Low heat price for solar heating plants**
- Ongoing efforts to develop solar collectors and solar collector fields
- Ongoing efforts to develop and demonstrate seasonal heat storage and to improve the interplay with the energy system