CEE Bankwatch Network

Case study on solar-thermal-based district heating in Dronninglund, Brønderslev Municipality, Denmark

For more information

Nataša Kovačević
District heating campaigner
CEE Bankwatch Network
natasa.kovacevic@bankwatch.org

Dronninglund solar heating plant with a solar collector area of 37,573 m².[1]

Introduction

Specific information[2]	
Solar thermal collector area	40,466 m^2 gross / 37,573 m^2 aperture with 2,982 panels
Thermal energy storage	Pit heat storage (seasonal storage) 61,700 m^3
Tank thermal energy storage (diurnal storage, load balancing)	865 m^3

[1] Photo: Testing, Development and Demonstration of Large Scale Solar District Heating Systems - Scientific Figure on ResearchGate, accessed 22 Apr, 2022.

[2] Franz Mauthner and Martin Joly, Analysis of built best practice examples and conceptual feasibility studies of solar thermal systems in urban environments, *IEA SHC,* 9, 31 August 2017.

Annual solar energy yield	17,201 MWh (06/2015-05/2016)
Solar fraction	48% (based on heat generated respiration final district heat output)
Specific annual solar energy yield	425 kWh/(m²gross·a) / 458 kWh/(m²aperture·a), 2015/2016
Length of the network	46 km (2016)
Number of consumers	1,350

Dronninglund's solar-assisted district heating system with seasonal pit heat storage was put into operation in May 2014. At the time when it was constructed, the Dronninglund solar farm was the largest solar plant in the world. It was considered innovative due to the way it integrated solar heating, seasonal storage and heat pumps. The plant reduced the carbon footprint of the conventional district heat supply and provided a stable price for heat from solar district heating.

The total investment costs for the plant amounted to EUR 14.6 million. The plant was subsidised by the Danish Energy Technology Development and Demonstration Program, EUDP, which supported the project with EUR 2.953 million. The payback period is 25 years.

Why solar plus storage was selected

Due to uncertain natural gas prices but also limited renewable resources such as biomass, the board of Dronninglund District Heating (Dronninglund Fjernvarme) decided on a strategy for a future heat supply based on high shares from solar thermal energy. There were several additional points to this:

- The main arguments for such a system were stable heat prices over the system's lifetime and more flexibility in district heating operations due to the new equipment (solar thermal + seasonal storage + absorption heat pump).
- It was also essential that the technology provided a cleaner environment; trouble-free operations (with demonstrated reliability over the last 25 to 30 years); and that the actors involved, including industry, were already sharing valuable experience in solar developments for district heating needs.[3]
- Additionally, the surplus savings Dronninglund District Heating obtained by installing the solar field meant that some of the savings could be sold on the 'energy savings stock market'.[4]
- An economic study showed that the project would meet the crucial demand for district heating in Dronninglund and that the investment would not increase current end-consumer costs for heat.[5]

[3] Dansk Fjernvarme / PlanEnergi, Solar District Heating Inspiration and Experiences from Denmark, *Dansk Fjernvarme / PlanEnergi*, January 2018.

[4] All grid and distribution companies in electricity, district heating and natural gas is through the Agreement of 13 November 2012 /6/ required to achieve a number of energy savings annually and report these to the Danish Energy Agency (DEA). The first year's solar heat production could count as such an energy saving. The system includes the opportunity to buy other companies' savings instead of obtaining them.

[5] Dronninglund Fjernvarme, Dronninglund Solar thermal plant, *Dronninglund Fjernvarme*, 2015.

Technology and investment costs

Dronninglund District Heating's solar thermal plant consists of 2,982 solar panels, or 37,573 square metres (m^2). The panels are divided into fields, each connected to a heat exchanger in the technique building. The maximum power that can be obtained from the collector fields is 26 megawatts (MW) – this can be compared to the maximum consumption, which is 12 MW in the coldest winter periods.

Each row of the collector fields has 21 solar collectors connected in sequence. Cold water is heated gradually by the solar collectors. This ensures that the temperature in the last solar collector of the sequence is as decided in the control system. The solar collectors are mounted on galvanised steel profiles processed into the ground. The tilt of the solar collectors is 35° to maximise the annual solar yield. Twenty-one collectors per row is a typical number for arrays with harp-type collectors,[6] as in Dronninglund, as the pressure drop becomes too high or the flow velocity becomes too small in the manifold pipes (hubs that connects supply and return lines) if more collectors are connected. The inlet temperatures of the collector array are around 40 °C in summer and can drop to around 15 to 20 °C in winter. Outlet temperatures reach 8 to –90 °C in summer and typically 30 to 40 °C in winter[7].

The seasonal pit thermal energy storage, which has a volume of 62,000 cubic metres (m^3) (91 by 91 by 16 metres), was built in an abandoned gravel pit. The ground water level is approximately three metres below the bottom of the storage area, and the soil consists of gravel and sand. The storage pit is insulated on the top with a floating cover. Insulation for the area separates the water from the units. The storage is combined with an absorption chiller (2 MW of cooling capacity), which will work as a heat pump to allow the network to use the low-temperature heat. The storage is charged to 85 °C during summer and discharged to 10 to 15 °C during winter. The storage is used directly and as heat source for the absorption heat pump. Therefore, the network's temperature[8] can get as low as 15 °C, making even solar heat at 30 to 40 °C a valuable resource in wintertime (usually between November and February).

Investment and operation costs

The total investment costs for the plant amounted to EUR 14.6 million, of which EUR 6.1 million were invested in the solar installation. Dronninglund District Heating completed the project on budget; the company Arcon-Sunmark, which delivered the collectors and support structure for the solar field, achieved 30 per cent of the

[6] Design is usually used in low pressure thermosyphon systems or pumped systems. Philip Ohneweina and Robert Hausnera, A Novel Approach to the Analysis of Hydraulic Designs in Large Solar Collector Arrays, *Energy Procedia,* 6-7, 25 September 2013.

[7] Daniel Tschopp et al., Large-scale solar thermal systems in leading countries: A review and comparative study of Denmark, China, Germany and Austria, *Applied Energy*, 6 April 2020.

[8] Low Temperature District Heating (LTDH) system is defined as a system of district heat supply network and its elements, consumer connections and in-house installations, which can operate in the range between 50-55°C to 60-70 °C supply and 25-30°C to 40°C return temperatures and meet consumer demands for thermal indoor comfort and domestic hot water.

cost savings[9] (or 155 m^2 of the solar field), by optimising the product and construction. One of the major advantages of the pit heat storage is that the cost per cubic metre of storage is relatively low, e.g. around EUR 40 / m^3. A larger storage pit than the one in Dronninglund has achieved even lower costs than this (between EUR 20 and 30 / m^3).

Economics of the solar thermal plant	EUR, thousands
Heat storage, 62,000 m^3 (EUR 38.7 / m^3)	2 400
Buildings	2 400
Solar panels	6 100
District heating pipes	1 340
Boiler plant and heat pump	920
Building interest and contingencies	800
Total investment hardware	13 960
Consulting engineers	673
EUDP (subsidies from the Danish Department of Energy)	-2 953
Netto investment (municipal guarantee for loan)	11 680

Operating expenses are low, amounting to approximately 15 cents per megawatt hour (MWh) of solar.

The production price for heat in Dronninglund has no subsidies included. Capital expenses correspond to the average costs for a 20-year annuity loan with an interest of five per cent and two per cent inflation.[10] The heat price for consumers today is DKK 424 / MWh, excluding VAT (~ EUR 57 / MWh).

Operational experiences and efficiency

The company's experience with respect to the operation of the plant has been that a solar district heating system is easy to operate. Operations can be done by regular staff.

[9] The typical investment costs of a ground-mounted 10,000 m^2 collector field were 200 EUR/m^2.

[10] Dronninglund fjernvarme, Annual financial report of Dronninglund fjernvarme 1/6 2013-31/5 2014, *Dronninglund Fjernvarme,* 2014.

The performance and efficiency evaluation of the Dronninglund solar district heating plant from 2014 to 2017 found that the plant's efficiency is 39 to 41 per cent and the PTES storage system's efficiency was 90 to 96 per cent, which proves the efficiency and reliability of the storage technology. An evaluation of performance confirmed that the integrated thermal storage practices had a good balance of usage of the temperature ranges compared to the previously existing district heating supply of the connected district heating networks. Also, evaluated solar fractions, used for charging the seasonal storage, were in line with the planned project expectations.[11] Heat losses from the storage pit turned out to be lower than expected for all years. One positive impact in this sense is the low temperatures in the winter period, which result in negative thermal losses in the bottom part of the storage pit.

Integration of the solar system into the existing district heating network

In the long run, Dronninglund District Heating planned to provide all of its heat through renewable energy to keep heat prices stable. Currently, the heating network's supply is based on four combined gas-based heating plants (7 MW_{el} and 12 MW_{th} total) and two biofuel boilers (15.1 MW total).

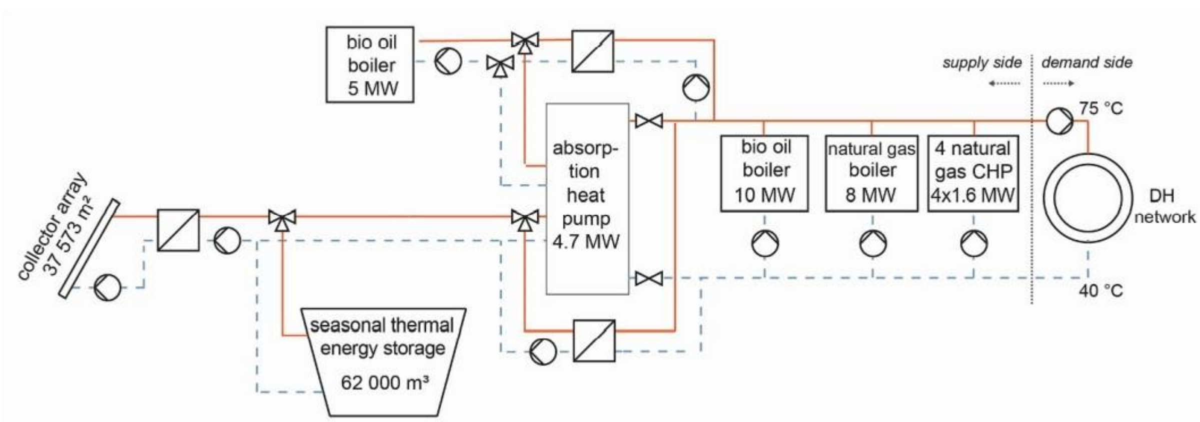

Fig. 2. Hydraulic layout (simplified) of the Dronninglund district heating system, Pumps indicate flow direction in inlet/return pipes with lower temperatures (blue dashed lines) and outlet/supply pipes with higher temperatures (red solid lines) (source: Solites)

Decision, design process and approaches applied

Dronninglund District Heating is a consumer-owned cooperative. In 1989, this cooperative became the first Danish district heating company to install natural-gas-driven engines for combined heat and power production.

[11] Carlo Winterscheid and Thomas Schmidt, Dronninglund District Heating Monitoring Data Evaluation 2015-2017, *Solites*, 31 May 2019.

In 2005, the board and general assembly of Dronninglund District Heating realised that the cooperative should replace natural gas with renewable energies.

In 2007, Nordjyllands Vækstforum (the Danish governmental forum for regional growth) subsidised a pre-feasibility study which showed that a large-scale solar thermal system with seasonal heat storage could cover up to 50 per cent of the heat demand. A prerequisite was that the heat was not allowed to be more expensive for consumers.

Five years passed between the idea in 2006 and the decision in 2011, during which solar oriented shareholders built confidence among other shareholders using facts and clear information. Additionally, Dronninglund District Heating's board maintained close dialogue with the municipality, whose environmental official was designated to participate in all meetings on the solar district heating project. The municipality benefited from the fact that the solar system would help meet the city's climate objectives.

Dronninglund District Heating applied for a subsidy from the Energy Technology Development and Demonstration Programme (EUDP), a programme financed by the Danish state. The SUNSTORE 3 project application was approved and a subsidy was granted for the detailed design of the project and for investments in long-term storage, piping, heat exchangers and a control system to connect the production units.

The detailed design was organised in such a way that one of the project partners, PlanEnergi, was responsible for simulating the overall energy system, moisture calculations, etc. and conducting experiments in connection with the lid design. The other partner (NIRAS) designed pipes, pumps, heat exchangers, valves, etc. in detail; prepared the drawing and tender material; and was responsible for the tender evaluation and contract negotiations. The first step in the process was to draw up a system diagram. Then a model of the total energy system was built in the simulation programme TRNSYS, after which the system could be optimised for flow, temperature conditions, etc.

The detailed design and preparation of tender material was carried out in early July 2010 and the tenders were received in August 2010. However, the solar collector field had been tendered in the autumn of 2008 even before the project started. The contract negotiations were completed and contracts written in December 2010.

For the seasonal heat storage, there was a slightly different process, as the design process was carried out as a partnership with GG-Construction as contractor and NIRAS and PlanEnergi as project developers. Throughout the process, there has been close collaboration with the municipality of Brønderslev (where Dronninglund is located) both at the political and administrative levels, which was necessary for such a complicated project to be implemented.

The project approval began in December 2009 with a pre-publicity phase for the local plan, with the project site location north of Nordre Ringvej. When doubts arose about this location in the spring of 2010, the municipality of Brønderslev conducted an environmental screening.

No important complications arose during the process of obtaining the building permits. Fees for processing and approvals were low due to the fact that the project would construct only one building, with the rest technical systems.

A significant barrier for establishing the solar district heating system in Dronninglund was obtaining a piece of land, as well as objections to the local plan forwarded to the Nature and Environmental Appeal Board. This challenge was overcome by several discussions organized between the local government and communities, while detail environmental assessments were undertaken. This delayed the project by a year to a year and a half, but the environmental and social quality of the project improved.[12]

Summary and lessons learned

Several lessons were learned during the planning and building of the Dronninglund solar plant:

- It is not strictly necessary to build the maximum/optimum size plant from the very beginning – the establishment can be done in stages, and further stages can then be done when there is good operational experience with first stages (although developing a full-size plant in one go will probably be the most economic decision).
- The greater the heat demand, the better the economy. This means that there is a scale advantage of solar heating systems – and especially for seasonal pit storages. Solar fractions[13] more than 60 per cent are technically and economically possible. The combination with heat pumps can improve the economy, but must be analysed specifically for each project.
- The optimal plant size should be investigated based on the local characteristics of the specific district heating supply and network. The size could be limited by the available land area. For larger solar thermal systems, it is possible to establish longer transmission lines, as the economy for the bigger solar system can better carry an increased investment for a longer transmission line.
- The solar system can be expanded in stages. If so, it is appropriate to take this into account when planning the first stage, e.g. by positioning the first field in such a way that expansion is easy.
- When the project idea containing the main economic, social and environmental parameters is available, and if the board wants the project initiated, the proposal is put forward to the general assembly. Before this meeting it is important to inform the users (the public), the municipality and possibly the landowners affected by the project.
- The content of this project idea will often be partially coincident with a project description where the economy for the project is illuminated.
- A project proposal must be prepared according to the national regulation, which imposes formal requirements for illuminating certain aspects of the project (economy, environment, etc.).

[12] PlanEnergi, SUNSTORE 3 Phase 2 Implementation, *Dronninglund Fjernvarme*, March 2015.

[13] Percentage of the hot water load that can be met by solar energy on an annual basis

- A project proposal must be approved by the local authority and submitted in public consultation before the solar system can be established. Thus, dialogue with the municipality as early as possible in the process is very important.
- The municipality plays an important role in the coordination of the project, assessment of optimal location, local and municipal regulations and acquisition of land – is the municipality willing to expropriate land? Environmental screening, environmental permits and building permits are also important elements prior to establishing the solar district heating system.
- If a district heating company decides to establish a pit heat storage system and considers different size options, then the cost of increasing the volume with an extra m^3 can be very low (e.g. in the range of EUR 15 to 20 / m^3). When considering large-scale storage systems, the investment cost will typically be much lower than steel tank solutions. On the other hand, the initial investment cost of a pit heat storage together with the associated heat losses makes it unfeasible for smaller storage volumes (e.g. a few thousand m^3).

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