Eco-Energetics: technologies, environment, law and economy
2019 · Vol. 2 · pp. 19–28 ISSN 2657-5922 · Annual
DOI 10.24426/eco-energetics.v2i2.106

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Low temperature district heating using waste heat from biogas plant

Abstract
A biogas plant can be a source of waste-heat flows with different thermal parameters. Application of such flows in local, low-temperature district-heating networks is a very attractive option for highly efficient, energetically and economically, co-generation systems applying biogas as the primary energy source.

Keywords: low-temperature district-heating network, biogas installation, co-generation, energy efficiency.

1. Introduction

We are living in a period of crucial changes in district heating (DH) systems. Developed and built in years 1930–1970 2nd Generation DH (using supply temperature above 100°C and coal as main energy source) has been replaced later by 3rd Generation DH using coal, biomass and wastes as energy primary sources and lower supply temperature in the range 80–100°C. The 4th Generation (Svendsen et al., 2017; Walnum & Fredriksen, 2018) is waiting at the door, with some pilot installations already done in Denmark (Olsen et al., 2014), England (Wiltshire, 2011), Norway (Line, 2013), Belgium (Svendsen et al., 2017), Finland (Rämä & Sipilä, 2016), Germany (Walnum & Fredriksen, 2018; Reinholz, 2019) and other countries. It should enable lower grid losses (due to decreased supply temperature, below 70°C), integration of renewable heat (from solar, geothermal, wastes and biomass sources) and integrability with cooling networks and smart energy systems. Moreover, at the same time 5th Generation DH is starting to be discussed integrating heating and cooling, enabling demand side response and related thermal energy storage and wider integration of waste/surplus heat sources (Jensen, 2016; Fifth Generation District Heating Networks. Trend towards lower temperature distribution circuits, 2018). Some new, innovative ideas of integrated district heating and cooling networks are being developed, e.g. Ectogrid™ to be implemented by *EON Sverige* AB (Strömberg, 2018).

The role of district heating (especially Low Temperature DH-LTDH) in decarbonization of future EU energy systems was discussed by Connolly et al. (2014) and Lund et al. (2014). These LTDH systems will allow utilization of waste/surplus heat from industrial and waste-to-energy systems, and use of geothermal and solar thermal heat. The technologies converting solid biomass into bio(syn)gas as well as liquid biofuels will also play an important role in future "smart energy systems". These systems will be characterized by a high degree of integration between district heating, cooling, electricity and transport fuel, leading to possible synergies among them.

An important source of surplus heat for LTDH could be biogas installations. Wegner (2015) and Ritz (2015) discussed the issue of heat utilization from biogas cogeneration systems pointing to potentials for district heating and cooling. Table 1 presents potential methods of heat utilization for heating human and agricultural houses, drying, cooling and additional electricity production (e.g. in ORC or Kalina cycles).

Table 1. The methods of waste heat utilization from CHP in biogas plants

Option	Heating	Drying	Cooling	Electricity production
Uses	District heating	Drying wood, wood-chips, and pellets	District cooling	Additional electricity production with CRC, ORC or Kalina technologies
	Heating of stables	Drying agricultural products	Cooling of buildings	
	Heating of greenhouses	Drying digestate and sewage sludge	Cooling of stables	
	Heating for aquaculture		Acclimatisation of food storage buildings	
	Heat transport in containers		Process cooling	
	Other heating options			

Source: Sustainable Heat Use of Biogas Plants, A Handbook 2nd edition, D. Ritz, 2015, retrieved from: http://www.biogasheat.org/wp-content/uploads/2015/03/Handbook-2ed_2015-02-20-cleanversion.pdf; also: Sustainable Heat Use of Biogas Plants, *Questions & Answers*, I. Wagner, 2015, retrieved from: http://www.biogasheat.org/wp-content/uploads/2015/03/BiogasHeat-Questions-and-Answers-Brochure.pdf.

The aim of this work is to present the pilot LTDH installations showing their potential as surplus-heat consumers for any biogas plant. Such LTDH systems can contribute to effective utilization of various heat streams from biogas-CHP systems. The effective utilization of available heat streams influence in a crucial way economics and environmental significance of biogas installations, including those with heat storage systems (Cenian et al., 2017).

2. Pilot installations

Three pilot LTDH installations will be presented including the largest Danish installation (560 modernized houses in Albertslund), the LTDH in Sonderberg district of Hoje Taastrup for non-refurbished houses and a planned ultra-LTDH grid in Kalundborg region.

2.1. Albertslund LTDH project

Albertslund, in 1980's rather poor municipality with high unemployment and social problems, is located in the region of Greater Copenhagen peripheries (suburbs). This Municipality (partly agro) counts 28,000 people living on a land area of 23 km^2. Nearly half of the housing belongs to commune and were built in early 60's and 70's; many need total renovation. In 1980 local policy makers decided to develop the plan aiming at region revitalisation as well as climate and environment protection. Having limited resources (large unemployment and social needs) the city administration decided to include citizens into the decision making group, in order to discover their priorities and make the decision process a bit easier. The "Brugergruppen" or "user group" helped the local politicians to find the best solution for the citizens and environment. Today Albertslund is known as living-lab for new eco-solutions, including energy and finance saving heating system, LED (DOLL) lighting and the intelligent city solutions. In the years 2006–2015 reduction of CO_2 emission surpassed 25%. New SEAP (Sustainable Energy Action Plan) envisions that by 2025 all space heating and electrical energy will be produced without CO_2 emission — by introduction of 4th generation district heating and better use of local energy sources (e.g. wind farms and heat pumps).

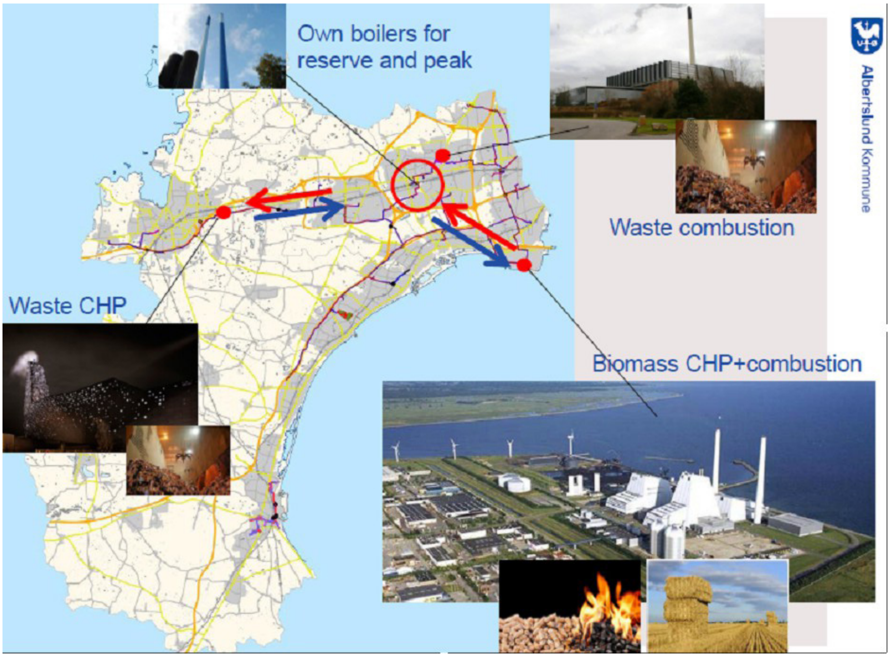

Fig. 1. Heat supply for district heating (Albertslund)

Source: Strategic actions to boost energy efficiency in a local climate strategy — Albertslund, The smart energy city, C. Oxenvad, 2018, Energy Efficient Cities Conference, Gdynia, retrieved from: https://www.imp.gda.pl/ee_cities/en/prezentacje.pdf.

Nowadays, the municipality is heated by a central heating grid supplied by waste incineration and CHP biomass combustion system (Fig. 1). The initiated measures combined LTDH application with complex renovation of communal housing resources. By 2026 LTDH is going to be implemented in the whole city. Before housing must undergo complex refurbishing (first the tenants, then private and industrial houses) and 380 km of worn and ineffective heat distribution pipework must be replaced by a new well insulated grid.

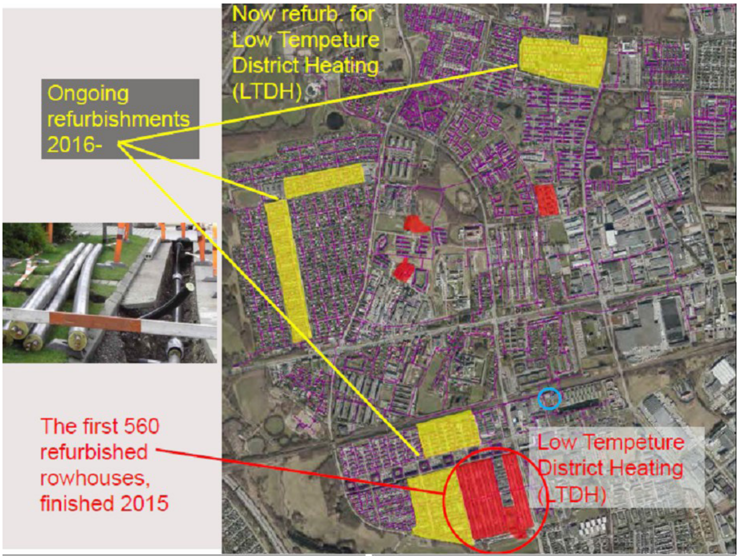

Fig. 2. Heat supply system for district heating (Albertslund)

Source: Strategic actions to boost energy efficiency in a local climate strategy — Albertslund, The smart energy city, C. Oxenvad, 2018, Energy Efficient Cities Conference, Gdynia, retrieved from: https://www.imp.gda.pl/ee_cities/en/prezentacje.pdf.

The first pilot project, performed at the old and economically weak housing department (560 houses), was finished in 2015 (see Fig. 2). It is the largest LTDH system in DK (and probably EU), presenting LTDH implementation for existing buildings with comprehensive refurbishment, which included: roof, wall and basement insulation ($\lambda = 0.020$ W/m K), floor heating system with additional new type radiator (2 or 3 layer LT radiators) with blowers. City supplies LTDH system with temperature 57°C at the heat exchanger of each house (see Fig. 3). The radiators are fed with water flux at 52°C and the floor system is subsequently fed with the return flow from radiators at 40°C. The return flow from the house is at really low temperature T = 30°C, i.e. the temperature drop in the house system equals ~ 27°C.

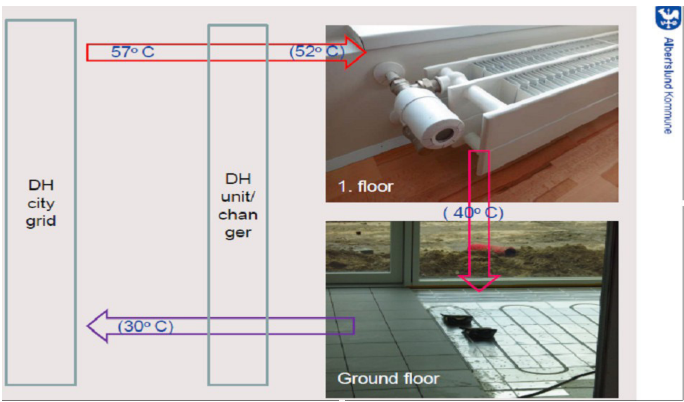

Fig. 3. Heating system in Albertslund LTDH housing department

Fig. 4. Albertslund renovated houses (right) in contrast to original state-of-art (left)

Source: Strategic actions to boost energy efficiency in a local climate strategy — Albertslund, The smart energy city, C. Oxenvad, 2018, Energy Efficient Cities Conference, Gdynia, retrieved from: https://www.imp.gda.pl/ee_cities/en/prezentacje.pdf.

The results of the renovation works are presented in Fig. 4 (left side before and right side after renovation). The heat supply and its costs decreased about 50% — this enables a credit handling using ESCO model, i.e. from savings on the heating bill.

2.2. Hoje Taastrup municipality suburb of Copenhagen

Høje Taastrup municipality (with 48,500 inhabitants) is known for its green transformation agenda. By 2050 the region is going to be 100% carbon free. The municipality is composed of small housing areas, with family houses, row houses and some multifamily houses, most built between 1960 and 1990. The city authorities developed plans and measures for refurbishment of different housing types. About 50% of the houses are connected to the heat grid, the rest employ gas and oil boilers. The city aims at the LTDH and heat pump popularization based on local heat and waste heat (from industry) utilization.

One of the issues to be tested is LTDH introduction in non-refurbished buildings. It is generally assumed that it is not feasible (technically and economically) that all buildings in DK will be refurbished to high energy standards in the timeframe of 2035–2050, when LTDH is going to be introduced. Is it then possible to connect a housing district to LTDH, before the whole housing stock (of a certain type) is renovated to low energy standards?

The company Høje Taastrup Fjernvarme a.m.b.a. developed a pilot LTDH in the district called Sønderby — built in 1997–98, using return water flow from the neighbouring area as the main supply ("cold supply") for the system. The network includes 75 existing detached houses (110–212 m^2 living area); the total heated area of 11,230 m^2 with under-floor heating. When the return water temperature is not sufficient for the LTDH-network, a portion of hot water from the "hot supply" (normal utility supply) is added in the mixing shunt. The "cold supply" has provided heat in the range of 30–67°C

(48°C in average) — highest during summer. The “hot supply” has provided heat in the range of 65–107°C (80°C in average) — lowest during summer. The measurements show that the “cold supply” has covered 81% of the total supply to the LTDH system.

Fig. 5. Family buildings in Høje Taastrup

Before the LTDH was introduced the distribution pipelines — pair of single pipe with plastic media pipes were replaced as the existing annual network heat losses accounted for about 38–44% of the heat delivered from the central heat exchanger. The TwinPipe system, series 2, size 76 and smaller with Logstors alarm-system X4, which provides a precise identification of leakage location, was applied in new pipelines. In all main (street) “conti-produced” twin steel pipes in insulation class/series 2 with heat conductivity $\lambda = 0.023$ W/(mK) are used. To connect individual houses to the LTHD grid, flexible twin alupex (aluflex) pipes in insulation class/series 3 with heat conductivity $\lambda = 0.022$ W/(mK) are used.

In each house new substations, an instantaneous water heater type, designed for a capacity of 32.3 kW (according to Danish standards) were installed. Due to regulation on safety in relation to bacteria the water content in each domestic hot water supply line, including the volume in the secondary side of the heat exchanger, is aimed to be below 3 litres. According to design, district heating supply temperature is 50°C for domestic hot water allowing water temperature above 45°C.

It was found that after investment heat losses decreased from around 40 to ~13%. Measured supply and return temperatures of the LTDH network were 55 and 40°C, respectively (which corresponded well to design values 55 and 27–30°C). At consumer substations, the temperatures were ~53 and 38°C, respectively (design 50 and 25°C). The temperature drop 15°C instead of 25°C (as designed) highlights some problems which should be considered in future projects. It was found that LTDH is quite sensitive to consumer habits (the bad ones — to large consumption). Significantly, it was proved that LTDH is possible to be applied in existing housing areas.

2.3. Ultra-LTDH project in Kalundborg region

Motivation for development of ultra-LTDH grid was related to a substantial amount of surplus (waste) heat in the densely populated and industrial region of Kalundborg. The considered problem was as follow:

> *Is it feasible and how to transfer low temperature waste heat for long distance in economically viable way?*

The software developed in Kalundborg municipality (Marhauer-Nimb, 2018) considers different scenarios: insulated transmission, uninsulated transmission, general and individual heat pumps as well as an alternative case — biomass boiler. The model is based on thermodynamic calculations and actual costs for grid components. Exemplary result of economy calculation, for long distance (20 km), low temperature LTDH (~300 K) with central heat pump, 19 km uninsulated transmission using PEX pipes to central heat pump, later insulated transmission (1 km) using ISO pipe at temperature 75°C, is presented in Fig. 6–7. It was found that the payback period for the considered investment for Danish conditions is around 12 years.

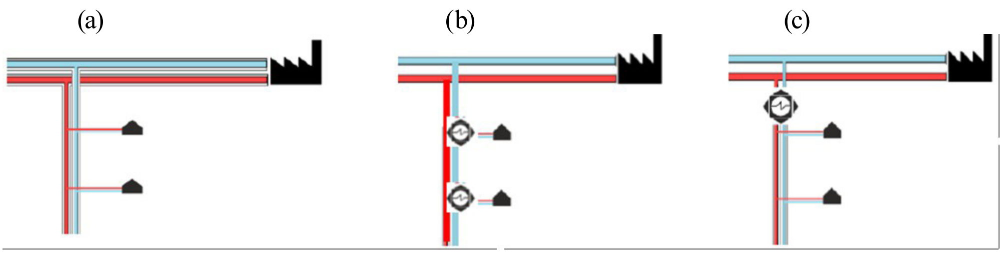

Fig. 6. The considered options: (a) insulated transmission, (b) uninsulated transmission line to the individual heat pumps, (c) uninsulated transmission line to the village and general heat pump (after D. Marhauer-Nimb, Energy Efficient Cities Conference, 2018, Gdynia)

EXPENSES

Expenses - S.2 Surplus heat, (low temperature)		
Investment		
Heat pump incl. construction, etc	60.517.527	DKK
Heat recovery		DKK
Heat exchanger system	20.000.000	DKK
Pumping systems	17.370.874	DKK
Piping transmission, PEX(Flow og return line)	23.799.400	DKK
Piping transmission, ISO	8.303.500	DKK
Piping distribution, ISO	-	DKK
District heating water	20.323	DKK
Subtotal	130.011.623	DKK
Loan		
Interest	0,0%	p.a.
Timeperiod	20	Years
Subsidies	-	DKK
Total	130.011.623	DKK
Depreciation		
Pipes	70	Years
Heat recovery and Heat exchanger system	40	Years
Pumping systems	30	Years
Heat pump	25	Years
Weighted Depriciation	39	Years
Variable expenses		
Pumping systems, operation (electricity consumpt.)	415.307	DKK/Year
Heating installation, maintenance	518.562,18	DKK/Year
Pipes, maintenance		DKK/Year
Heat pump electricity consumpt.	5.045.655	DKK/Year
District heating water	1.016	DKK/Year
Total	5.980.540	DKK/Year
Variable heat production cost	197	DKK/MWh

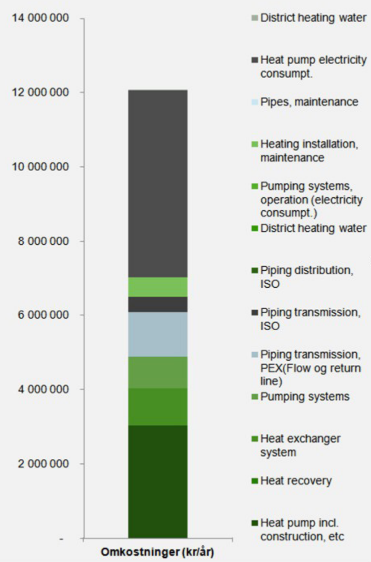

Fig. 7. Economy of long distance, low temperature LTDH (~300 K) — 20 km long distance (19 km uninsulated transmission using PEX pipes to central heat pump, later insulated transmission (1 km) using ISO pipe at temperature 75°C)

Source: Calculation tool. Utilization of surplus heat for DH, D. Marhauer-Nimb, 2018, Energy Efficient Cities Conference (pp. 17–18) Oct. 2018, Gdynia, retrieved from: https://www.imp.gda.pl/ee_cities/en/prezentacje.pdf.

3. Conclusions

LTDH grid is a sustainable solution for heat supply system using the various surplus heat sources, including biogas plants. The presented pilot projects have shown that the LTDH concept can be implemented even for existing buildings, especially when already equipped with underfloor heating as their space heating system.

The results show that it is possible to supply the customers with a supply temperature of approx. 50°C and satisfy both the space heating requirements and the safe provision of domestic hot water. The energy efficiency targets can be met. The distribution-network heat-loss has been confirmed as 13–14% of the total heat supply to the LTDH network. It is possible to solve Legionella problem by decrease of heated water volume (e.g. 3 l). Significant energy savings are possible by application of LTDH — in some cases even above 30%.

The good economy (10–12 years payback period) was found, for investment in long distance (20 km) ultra-LTDH (~300 K, below 30°C) with central heat pump; 19 km uninsulated transmission using PEX pipes to central heat pump, later insulated transmission (1 km) using ISO pipe at temperature 75°C.

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Acknowledgement

This article was partly supported by the LowTEMP project co-funded by the European Union (European Regional Development Fund & European Neighbourhood Instrument) in the frame of the Interreg Baltic Sea Region Programme 2014–2020.

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