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This paper describes the impact of using heat exchangers designed for operation at low supply temperature and at small logarithmic mean temperature difference (dT) compared to the level specified and applied today. Heat exchangers with a lower design dT in the consumer installation are designed for District Heating (DH) systems with reduced supply and return temperatures. This results in heat loss savings for the DH distribution network and increased energy conversion efficiency and power production at the DH plant. On the contrary investment cost is increasing in case of reduced temperature difference between DH flow and return. A key challenge for optimal and competitive DH system operation is reducing heat loss in the DH network. In most countries new building regulations require considerable reduction of heat consumption in individual buildings compared to earlier requirements. The ratio between network heat loss and heat consumption in buildings will even be more in focus in future. To address this challenge, the impact of applying heat exchangers operating at low dT in consumer installations and low supply temperatures is analysed. Further, the potential of using surplus heat is increased as the temperature levels decreases.

Introduction

Denmark aims at 100% renewable energy supply in 2050. DH is one of the solutions how to achieve this goal. Well-known advantage of DH is the possibility using surplus heat from power plants, industrial processes and waste incineration, which otherwise would be lost. The incineration of unrecyclable waste in a CHP plant is a well-known solution to process the increasing volume of municipal waste, and in Denmark it covers 20% of heat demand for DH. More stringent requirements to the energy performance of buildings are introduced generally, and thus heat losses from DH network become a key issue for DH in the future. One central component in relation to the potential for reducing heat losses in the DH network are the heat exchangers placed in the consumer installation. The design conditions for the heat exchangers, for DHW as well as for space heating, determine the flow and temperature levels in the DH network, which are the main influencing parameters in regard to the DH distribution losses. The aim of this paper is to analyse how far it's economical to decrease the DH flow temperature. On one side the cost of the consumer substation increases, due to the increased heat exchanger surface needed to address the low temperature operation. On the other side the thermal loss decreases for the DH network while the investment in larger DH sizes increases. Finally the increased CHP plant efficiency increases when operating at lower DH flow temperatures (turbine condensing temperature). The optimal DH flow temperature level depends on the balance of the mentioned parameters.

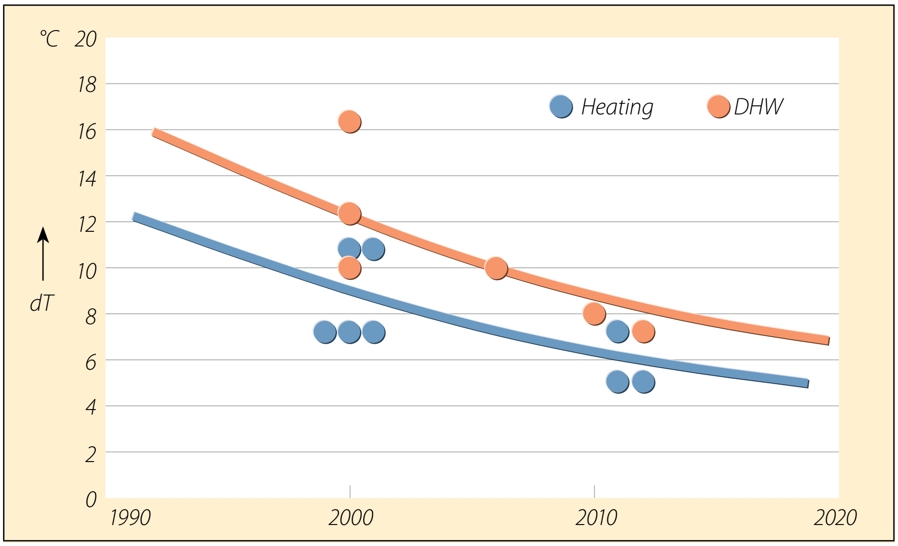
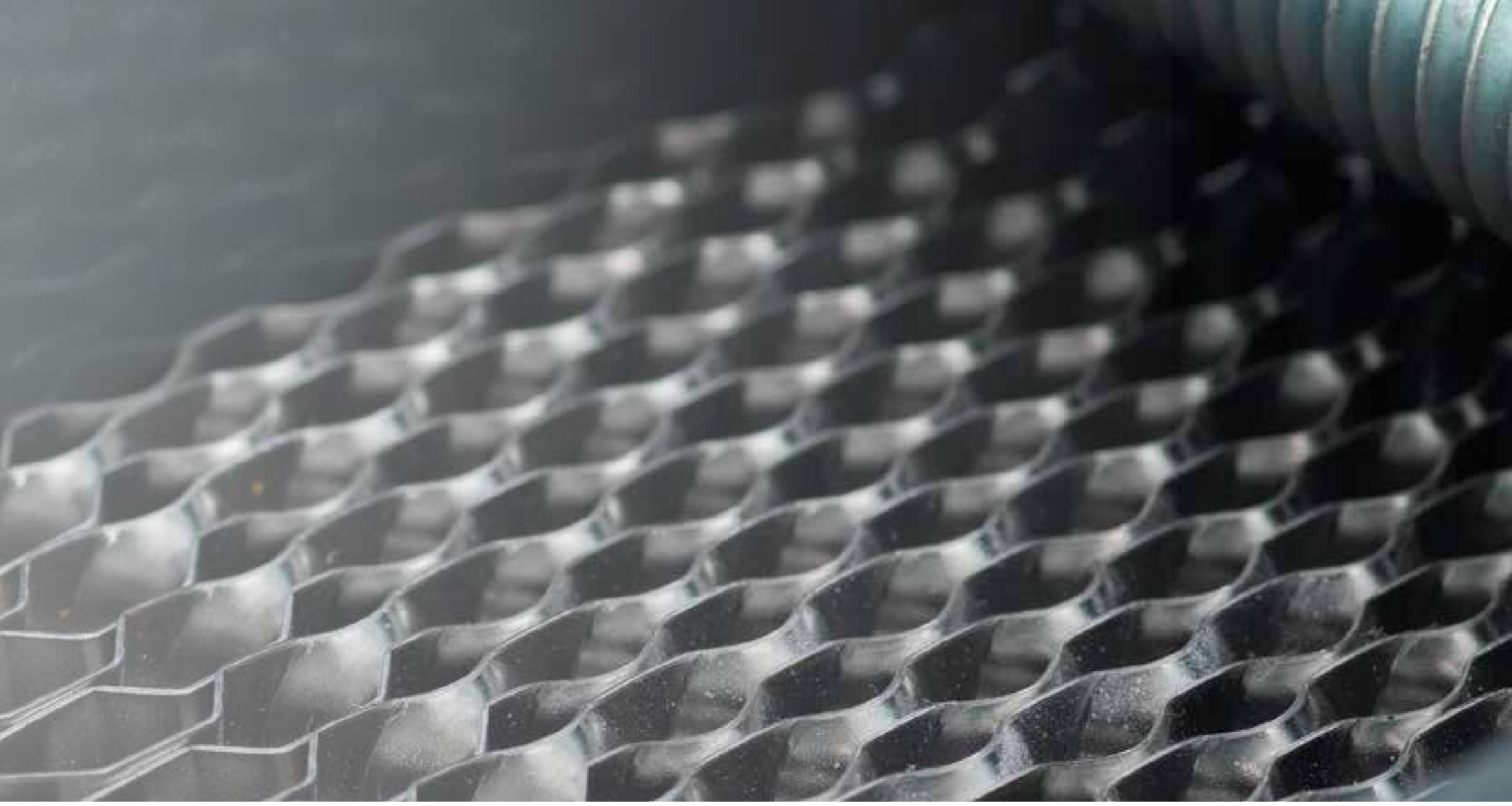


FIGURE 1: dT (logarithmic mean temperature) trend over time in Denmark

Heat Exchanger development

Previously shell and tube heat exchangers where widely applied. This type of heat exchangers typically needed a high dT for operation due to the low convective heat transfer coefficient on primary as well as on secondary side. When introducing the gasket plate heat exchanger more than 80 years ago, the convective heat transfer was improved and by this a reduced dT could be realised. A lower dT can in principle be obtained by all types of heat exchanger technology, simply by compensating the lover convective heat transfer by increased area. The advantage of plate heat exchanger in addition to the improved convective heat transfer is that the heat transfer area can be considerably increased without making the heat exchanger excessively large and costly. Typically the so called fishbone or chevron pattern was used. Later on, in the year 1977, the brazed heat exchanger was invented, anyhow still using the same plate design as the gasketed heat exchanger. The introduction of the brazed heat exchanger further reduced the costs. With the continuous heat exchanger improvements the costs is greatly impacted by the heat exchanger technology used. During operation of DH system the optimal dT at a specific point of time will depend on the balance between the improved overall DH system efficiency, costs reduction and the cost of the improved heat transfer for the heat exchanger. This can clearly be seen in Figure 1, which shows historical evolution of dT in Danish DH systems.



Based on the Danish data [1] there is clearly a tendency towards lower dT over time. An example of change for dT for heating could be 90/45 – 40/70°C to 70/30 – 25/65°C, and for domestic hot water (DHW) a change of dT could be 60/20 – 10/45°C to 52/20 – 10/45°C.

By the year 2005 a new plate design was developed by Danfoss, named the micro plate heat exchangers (MPHE) pattern [2]. With this world wide patented technology for heat exchangers has resulted in a higher heat transfer, lower pressure loss and reduced material consumption pr. transferred energy unit. The difference in performance is mainly a result of speed variation reduction for the MPHE pattern compared to the traditional chevronpattern, see figure 2.

As shown in figure 2, flow lines for MPHE have less speed variation compared to the chevron pattern. Looking at the green lines, it can be seen that the flow path for the MPHE pattern is 2D while its 3D for the traditional chevron pattern. This means a more streamlined and smooth flow through the profile which results in lower flow speed variations. The lower speed variation for the MPHE results in an average better heat transfer pr. pressure loss unit. This is because the high speed spots only result in limited increase in heat convection but significant increase in pressure drop [3]. By higher heat convection / pressure drop relation, bigger well defined brazing points can be afforded, leading to a stronger plate, which again enables a reduced plate thickness.

Looking at the consequences of reducing dT, as an example DHW preparation is analysed. The capacity is 33 kW, reflecting a typical one family house, and dT is variable. DHW is heated from 10°C to 45°C, where supply and return temperature are reduced accordingly to dT value. As it can be seen from figure 3, lowering dT has drastic impact on the needed heat transfer area, and thus on heat exchanger cost. There are tree curves, each representing a defined pressure loss for the heat exchanger. The lowest is a typical value of 10 kPa, where the two others represent rather high pressure loss compared to what is normally specified for consumer installations. Pressure losses for the curves are 50 kPa and 200 kPa, respectively. Additionally, the end user cost is included, and is related to the needed heat transfer area.

With figure 3 as the starting point, one relevant question is: what is the optimal dT, and what is the optimal pressure drop to be specified for the heat exchanger. For instance by setting dT constant and increasing the pressure loss from 10 kPa to 50 kPa approximately 37% of the heat transfer area can be saved. By increasing the pressure loss from 10 kPa to 200 kPa approximately 57% heat transfer area can be saved. This is practically independent of dT value. It is clear that the reduction of dT has strong impact on the needed heat transfer area, this simply due to the fact that the area goes to infinity when dT goes towards zero. On the other hand increased pressure loss requires increased pump work.

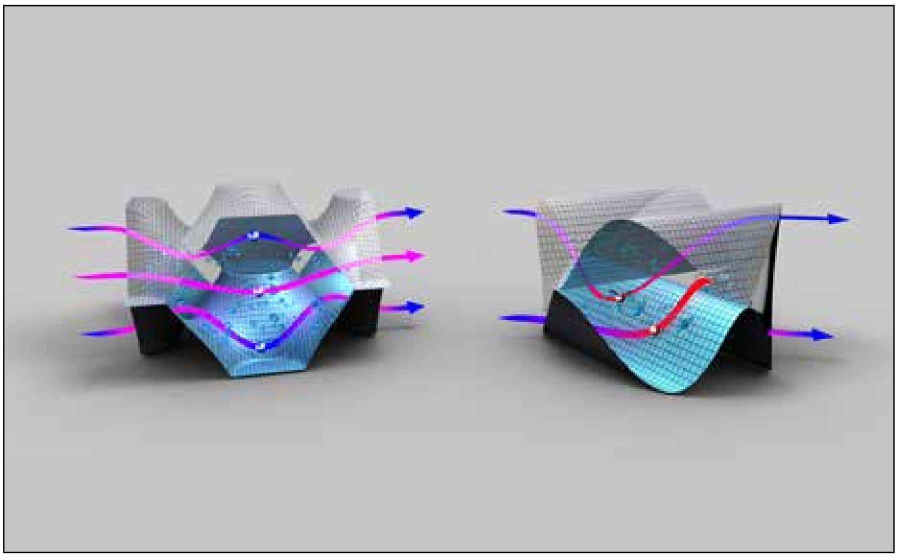


FIGURE 2: Heat exchanger plate profiles for Danfoss MPHE and traditional chevron pattern, including flow lines (units in mm)

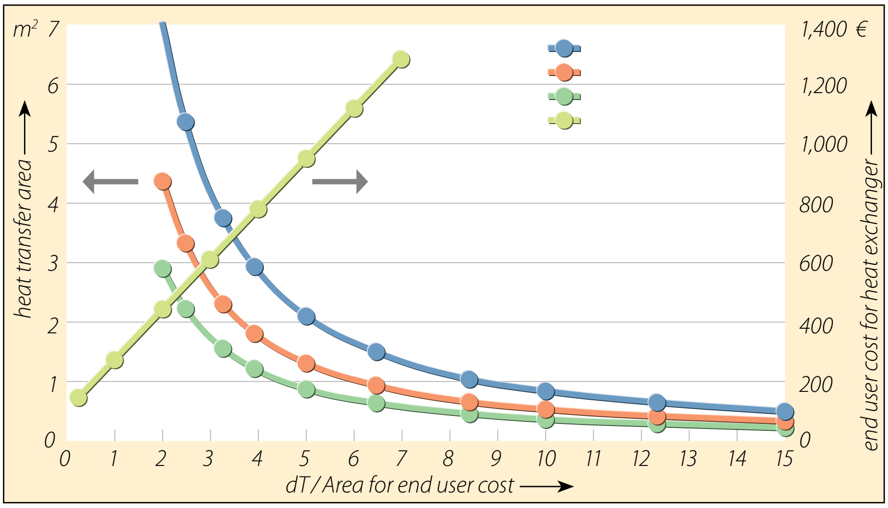


FIGURE 3: *Trade-off between dT, pressure loss, heat transfer area and end user costs*

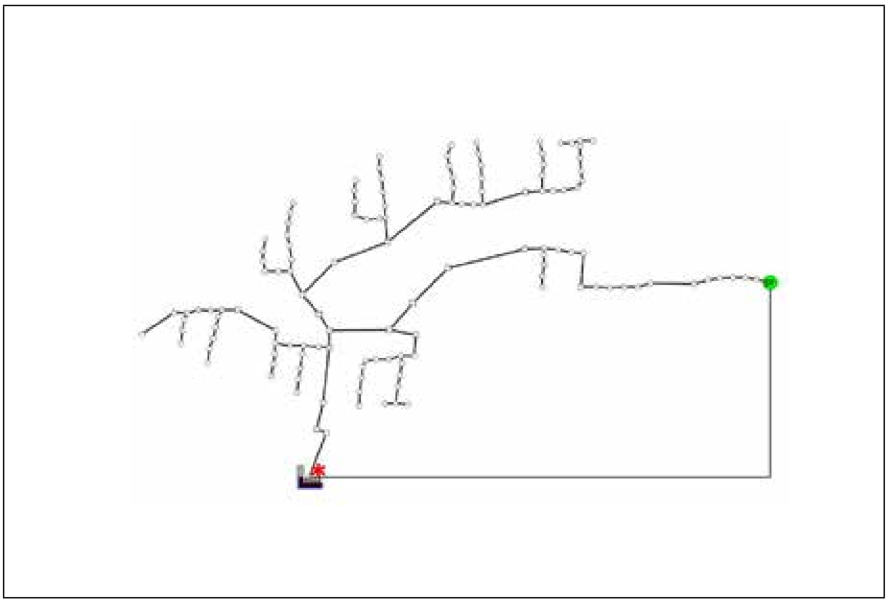


FIGURE 4: *The considered new built area – DH distribution network*

Temperatures for consumer installations

When quantifying the yearly performance of the consumer installation, especially the return temperature has to be addressed. The return temperature is a result of the influence from the DHW and heating circuit for space heating. The DHW return temperature depends on whether there is tapping of DHW or whether the system is running in idle mode, meaning no tapping. During idle mode, DH water is bypassed through a temperature regulated bypass thermostat, [4]. The bypass is affecting the DH return temperature during the non-heating season only. Two yearly sets of flow, supply and return temperatures are calculated, one with traditionally designed heat exchangers for DHW and heating, and one for future LTDH and low dT operation.

From table 1 it can be seen that the weighted DH return temperature is reduced from 36.4°C to 24.3°C. This is 12°C. The secondary return temperatures (TSR) are different for the two situations, this because towards the future it can be expected that the demands to the design temperatures for the radiators increases.

Temperature impact on DH distribution losses

This section highlights the advantages and possible disadvantages from a technical, economical and energy related perspective for LTDH networks compared with traditional district heating networks [5, 6, 7].

The low temperature system and the traditional district heating system are compared in a network system supplying new low energy houses fulfilling the Danish energy frame building regulation BR10 (2010) class 2015. The comparisons between the systems are based on simulations of a new built area.

The new build area consists of 116 family houses with a living area of 159 m2 each. All of the new houses build have floor heating. The temperature needed for space heating is therefore only 30–35°C. For domestic hot water the temperature requirement at the tap is set to 45°C.

In traditional systems and future LTDH systems with DHW storage tanks and without any temperature booster for DHW, the supply temperature must be 55–65°C, depending on the location of the DHW tank (primary or secondary side of the DH supply system, meaning if there is DH water in the tank or DHW in the tank). The legionella bacteria must be addressed with the DHW storage tank on the secondary side.
If consumer installations are equipped with instantaneous heat exchangers for the preparation of DHW, then 55°C is sufficient as DH supply temperature. For a LTDH with integrated heat pump for preparation of DHW the supply temperature can be even lower (practically down to 30°C which is fulfilling the floor heating temperature demands in low energy buildings. The heat pump then has to lift the DH temperature level used for DHW preparation up to 55°C. The analysed network is shown in Figure 4.

The annual heat demand for space heating and domestic hot water for the individual houses is shown in table 2. The difference between “Class 2015” and “realistic” is due to an increased and more realistic demand of DHW compared to the expected consumption in 2015. The figures related to “realistic consumption” are used in the analysis.

Figure 5 shows the heat capacity demand for a 159 m2 house as a function of hours in the year. The peak load is cut off in the figure corresponding to 3.4 kW. In order to optimise the network, it is an advantage to raise the supply temperature during peak load.

The network is dimensioned and operated such that the critical consumer has at least 0.5 bar of pressure difference. The temperature loss in the pipe network is an important issue. During peak load periods the temperature drop in the supply pipes are only a couple of degrees. But in the summer period where the demand is less than 10% of the peak demand, temperature drops of more than 20°C in the supply pipes have been experienced. The network should therefore be designed so that the critical consumer is supplied with a sufficient temperature.

Investment costs

Investment cost for a DH network is dependent on the temperature difference between supply and return in the peak period. Lower supply temperature

and lower dT between supply and return requires bigger DH pipes and more flow for delivery of the same amount of heat. The network investment costs are calculated for 4 variants of network supplying the 159 m2 group of one family houses. The investment cost for the traditional 80/40°C system considered is calculated to approximately 513,000 €. The investment costs for a supply system for a 65/25°C in comparison with the traditional supply temperature of 80/40°C is the same. A supply system with the temperature set 55/25°C is some 3–4% more expensive (approximately 155 € per house) and a system based on 45/25°C will be approximately 9% more expensive. (approx. 400 € per house).

The correlation between network investment costs and the difference in supply and return temperatures is shown in figure 6.

Heat losses and power consumption

The heat loss is dependent on the dimensions of the pipes and temperature levels in the network. As mentioned previously, it is necessary to design a network based on a simulation under peak load and then calculate how this network will perform in terms of heat losses over the year. The analysis is based on heat and peak demand for the group

1. Family house year 1970 – 150 m^2, 33 kW DHW capacity,average capacity 6.4 kW 1hr/day DHW pr. year 2300 kWh
Heating is active during 6 months, average heating capacity 3.5 kW 24 hr/day Idle bypass temp. set. = 35°C
For the future situation heating consumption for the house is reduced by a factor 3

	T DHF [°C]	T DHR [°C]	T SF [°C]	T SR [°C]	d Tlmn [°C]	energy/y [kWh]	DH flow [m^3/hr]	duration [hr/day]	duration [hr/year]	P av [kW]	duration [months/y]	T ret. weighted [°C]
traditional:												
HE	80	40	60	30	14.4	15000	0.075	24	4380	3.5	6	36.4
DHW tap. winter	80	16	50	10	14.9	2300	0.086	1	183	6.4	6	
DHW tap. summer	65	23	50	10	14.0	2300	0.131	1	183	6.4	6	
DHW idle	40	30	-	-	-	-	0.010	23	8395	-	12	
future:												
HE	55	25	45	23	5.0	5000	0.033	24	4380	1.2	6	24.3
DHW tapping	55	12	45	10	5.0	2300	0.128	1	365	6.4	12	
DHW idle	40	30	-	-	-	-	0.010	23	8395		12	

TABLE 1: Temperature sets for present and future consumer installation

		heat demand per year		
house 159 m^2	energy frame	space heat [kWh]	DHW [kWh]	heat demand [kWh]
	class 2015 frame	30 + 1000/A (kWh/y)		5570
	realistic consumption	4040	3200	7240

TABLE 2: Heat demand per house for the simulated group of houses

of 159 m2 one family houses. With floor heating in every house it is assumed that the return temperature for space heating is 25°C. This is a realistic value for new low temperature houses with focus on low return temperature. This would, however, not be the same for older floor heating systems. Heat loss on annual basis for a traditional supply (at 80–65°C) system is calculated to be 15–16%. The similar heat loss for a LTDH system is calculated to be around 8–11% dependent on the supply temperature 45–65°C and the actual system concept of the consumer installation., see table 3.

Table 3 also shows the needed network pump energy for distribution of the DH water in the different alternatives of network temperatures. The low temperature supply systems require more pump energy to secure sufficient temperature for the most critical consumer at the far end of the network. Finally the table shows the annual operational cost for each alternative network under the assumed energy prices: district heating price of 46.7 €/MWh and an electricity price of 130 €/MWh. A difference of 17–32% in yearly operation costs are calculated between the low temperature network concept and the traditional network concept. This corresponds in the case to 1,359–2,527 € in annual savings for a LTDH network. Per house it amounts to 12–22 €/year. It should be noted that table 3 does not include the costs of the consumer installation, e.g. the heat pump for temperature boosting.

Taking the increased costs for consumer installation and network into account the LTDH system cannot be carried on the economic value of the heat loss alone. The LTDH system must furthermore be justified on the value of low district heating temperature level seen from the production side.

Impact on heat generation efficiency due to lower temperatures

As the energy demand for new houses and buildings decreases the trend in district heating supply is towards lower supply temperature for minimizing energy losses. In Denmark district heating has a share of more than 60% of the entire heating market. Approximately 80% of the produced district heat is based on combined heat and power facilities. The central power plants have a share of approximately 50% of the total produced district heat. A LTDH system only requires a supply temperature of approximately 40–60°C and has a return temperature of 20–30°C, which in effect influences the CHP operation as the steam can be further expanded in back pressure turbines or in extraction turbines. Further, LTDH temperature sets allow a higher utilisation of the primary energy content of the fuel used. In a case example the electricity production of a back pressure turbine is increased by approximately 15 % at a DH supply temperature of 45°C instead of 80°C. As the value of electricity normally is superior over the value of district heat, it is an economic advantage to increase the electrical efficiency of the CHP operation.

If the district heat is produced in heat only production facilities, the possibility of higher utilisation of the primary fuel is important. Especially the possibility of flue gas condensation of the water vapour considerably increases the overall efficiency of the fuel conversion. This is especially relevant when using natural gas, wet biomass or municipal waste as these fuels have high water content.

It is reasonable to state that a LTDH system increases the primary fuel efficiency in the magnitude of 5–10 % resulting in similar savings for the annual production costs. The considered test house of 159 m2 needs 7.2 MWh/y at an assumed production price of 46.7 €/MWh, resulting in 336 €/y. 5–10 % hereof corresponds to 17–34 €/y per house.

Better integration of solar and geothermal energy resources

The integration of solar and geothermal renewable energy sources into district heating systems will be considerably improved by applying a LTDH system. Large solar thermal plants producing hot water for DH has become widespread in Denmark, mainly due to increased efficiency and beneficial taxation rules. The efficiency of solar panels is highly sensitive to the supply and return temperatures. If the mean water temperature in a solar panel is reduced from 60°C to 30°C the efficiency is increase by approximately 55 %.

In relation to geothermal energy, advantages are for example less deep boreholes to achieve a desired temperature and no or very limited absorption heat pump operation is needed. In general, a LTDH system enables a higher degree of utilization of geothemal energy as more locations become suitable.

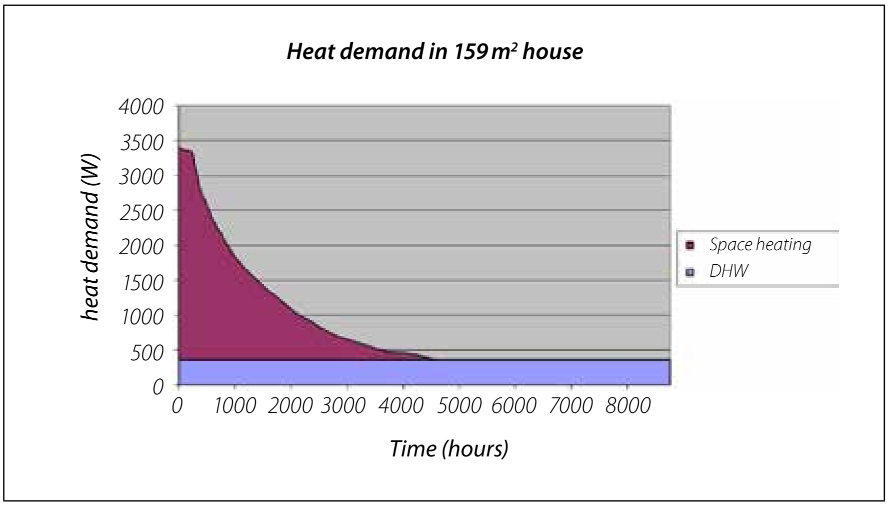


FIGURE 5: Heat load demand for the 159 m^2 detached house

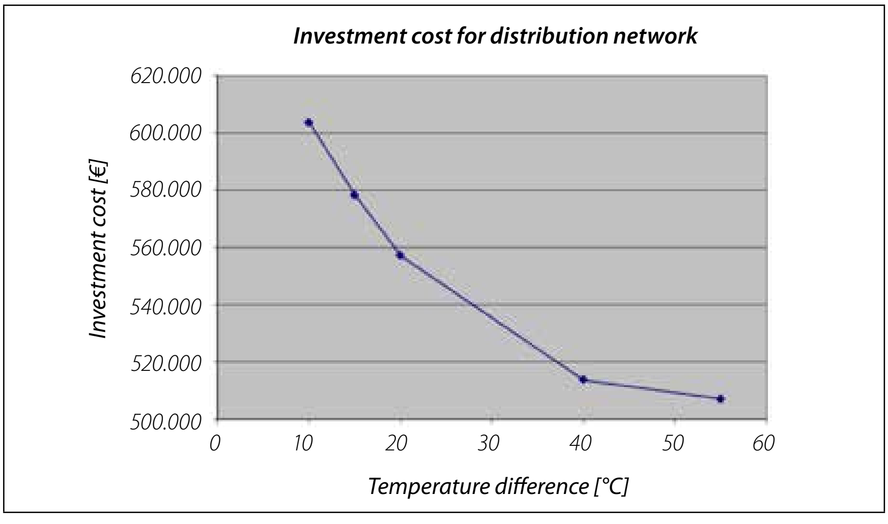


FIGURE 6: The network investment cost as a function of the temperature difference between supply and return

scenarios		heat loss in network			pump energy		operation cost	savings
		MWh	%	€	MWh	€	€	%
traditional network	supply 80°C	164,4	16,4	7.722	1,05	142	7.864	0
	supply 65°C	143,0	14,6	6.719	1,58	212	6.931	12
LTDH network	supply 55°C	132,9	13,7	6.243	1,95	262	6.505	17
	supply 45°C	104,0	11,0	4.886	3,36	450	5.337	32

TABLE 3: Operating costs for different district heating networks in terms of heat losses and pump energy consumption

primary temperature	80°C/40°C	65°C/25°C	55°C/25°C	45°C/25°C	
increased inv. cost heat exchanger/HP	0	0	250	1600	€/cons.
Increased inv. cost network	0	0	155	400	€/cons.
reduced distribution costs	0	8	12	22	€/cons. year
increased heat generation efficiency	0	10	20	30	€/cons. year
simple pay back time	n.a.	0,0	13	38	years

TABLE 4: Simple payback time for applying LTDH for various temperature sets

Cost balance for reduced DH temperatures

Table 4 includes examples of the cost balance for a family house regarding investments and operational costs when applying LTDH.

Based on this the DH network flow temperature could go down to 55°C. The calculated simple pay back time is 13 years seen from the heating company/society point of view. This shall be seen in relation to the life time of the DH network which is in the range of 50 years. The consumer installation has a typical lifetime of 20 years. In relation to the payback time of 13 years, it has to be mentioned that the future energy price probably will go up and requirements to system energy efficiency will increase towards the future. Reducing the DH flow temperature even further increases the investment costs due to the heat pump for DHW. In this case the simple pay back time is extended considerably. In this regard it has to be mentioned that the heat pump unit will still be attractive to use in the far end of the network where DH supply temperature and pressure is limited. Also where the target is to reuse low temperature renewable sources, this alternative is relevant. At a first look it could be obvious to conclude that the 65°C/25°C DH temperature is optimal, since savings are obtained without any investments. But it should be remembered that energy loss should be reduced and energy conversion efficiency should be increased, to secure future competitive DH solutions. The optimal dT value for the heat exchanger is not exact and depends on a number of boundary conditions. Based on the assumptions above, it's in the range of 5°C. A lower specified dT will drive the heat exchanger cost up, figure 3, and the related reduced distribution costs, table 3, and increased heat generation efficiency will not be able to compensate this. Anyhow for special conditions a lower dT can be optimal as well.

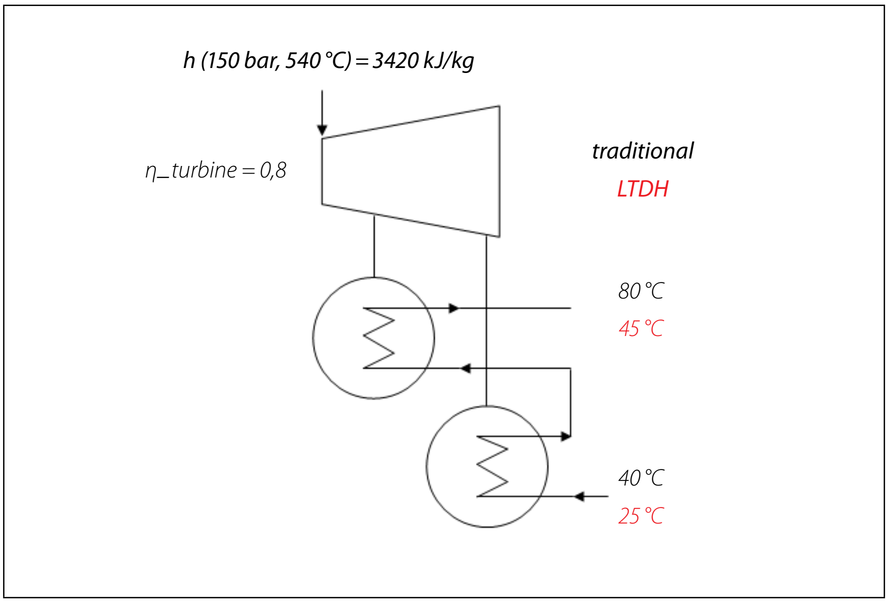


FIGURE 7: Example of back pressure turbine for DH supply

Conclusions

Based on the assumptions stated in this paper, it's from an economic point beneficial to specify heat exchangers with a low dimensioning dT value, compared to what is recommended in traditional DH nets today. Furthermore it's economical beneficial to apply LTDH, to a certain DH supply temperature level. The example included, states that a flow temperature of 55°C is still economical favourable. Ongoing work and research is investing the profitability of lowering the supply temperature further to 45°C. Regarding system energy efficiency, lower DH supply temperatures are to be preferred.

Traditional DH heat exchangers operate at dT in the range 10–15°C. The future recommendation is a dT value in the area of 5°C. This value is, however, based on some uncertainty and might over time change depending on energy and technology costs. Typically for the future, even lower dT are assumed to be the preferred option, and it fits to the general trend that is historically seen.

For the concept of DH compared to individual heating solutions, it's crucial to stay competitive towards the future reduced heat demands specified in the building energy envelopes. LTDH and heat exchangers operating at low dT is an attractive way for the DH concept to meet this challenge of the future.

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