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Lowering Temperature Regime in District Heating Network for Existing Building Stock

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Introduction of 4th generation district heating (4GDH) concept is an enormous challenge for district heating (DH) companies in Latvia, since most of the DH systems currently operate at high temperature regime. Therefore, this work analyses the possibility to lower the temperature regime of DH network in existing built-up areas. All stages of the DH system were included in the developed model – heat source, distribution networks and final consumer. The evaluation of various scenarios is done using energy efficiency, technological and financial indicators. Results show that switching to a lower temperature regime can reduce distribution costs and increase overall heat production efficiency. Therefore, in the situation when heat energy consumption in the existing buildings decreases, the current DH system (with high temperature regime) becomes inefficient, where specific distribution costs increases by more than 50 %. This work concludes that 4GDH concept has a high potential in the future, because the implementation of this concept is closely related to the energy performance of buildings.

1. Introduction

In the last decade energy efficiency increased significantly in district heating (DH) systems; this increase partly is caused by the introduction of 4th generation DH (4GDH) concept (Lund et al., 2014). Ziemele et al. (2014a) and subsequently in Ziemele et al. (2015) analyzed the benefits of a low temperature DH system in the regions of energy efficient buildings; the results showed various benefits, such as, decreased distribution heat losses, improved efficiency for the use of alternative energy sources (Dalla Rosa and Christensen, 2011), possible use of low potential industrial heat (Jurgensen, 2011) and cheaper materials for the distribution network in the comparison to a high temperature DH system.
As for now, most of research studies the transition to a lower supply temperature regime in a newly built and up to build area (Ommen et al., 2016). For example, various temperature regimes and substation scenarios were compared for Austria by Kofinger et al. (2016). Several authors (Gong and Werner, 2015) and also discussed in (Baldvinsson and Nakata, 2016) included exergy analysis to account for the different temperature levels used in DH systems.
Nevertheless, little research is done to study the effects, when the temperature regime is reduced in existing DH network. Therefore, the main aim of our research is to analyze the possibility to lower the temperature regime of DH network in existing built-up areas; the evaluation of various scenarios is done using energy efficiency, technological and financial indicators.
Research results are applicable for the introduction of 4GDH concept, since this concept possesses an enormous challenge for district heating companies. Especially this issue is important to the countries similar to Latvia, where most of the DH systems operate at high temperature regime.

2. Case study

The research is based on the case study of boiler house in Riga, Latvia. The operation of this boiler house is studies for 3 year period (2011-2013). For heat production two natural gas boilers with capacity of 2.5 MW for base load are used; and additional natural gas boiler of 1 MW is used to cover peak loads only. Heat from flue

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gas is recovered using flue gas economizer. Heat is distributed using 115 °C supply and 70 °C return water temperature (115/70 temperature regime).

The main heat consumers are apartment and industrial buildings. The average amount of produced heat energy is 900 MWh per month in the winter period and 116 MWh per month in the summer period. The amount of heat energy produced in the winter period covers the load of domestic hot water and space heating in apartment buildings and also the space heating requirements for industrial buildings. In the summer period, produced heat energy is used to supply domestic hot water for apartment buildings only. The comparison of the projected and historical heat load patterns for the boiler house are shown in Figure 1.

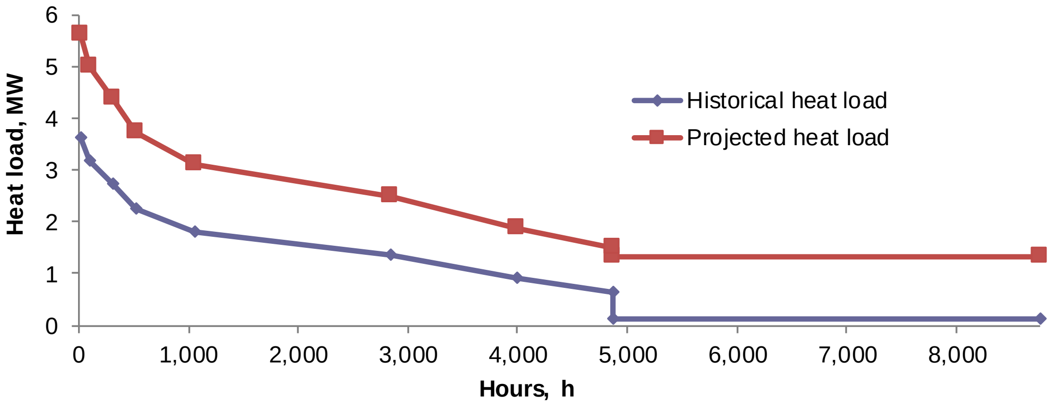

Figure 1: The difference in the projected and real heat load for studied boiler house

The projected heat load is about 1.5 times higher than the historical heat load in the winter period and about 9.5 times higher in the summer period (see Figure 1).

Data analyses was done to evaluate the operation efficiency of the boiler house. The total heat losses in the DH network reaches up to 110–125 MWh in the winter period and about 13–16 MWh in the summer period. Thus, heat losses accounts for up to 15–20 % in the summer period. Figure 2 shows the correlation between specific heat losses and the amount of produced heat and between specific electricity consumption and the amount of produced heat.

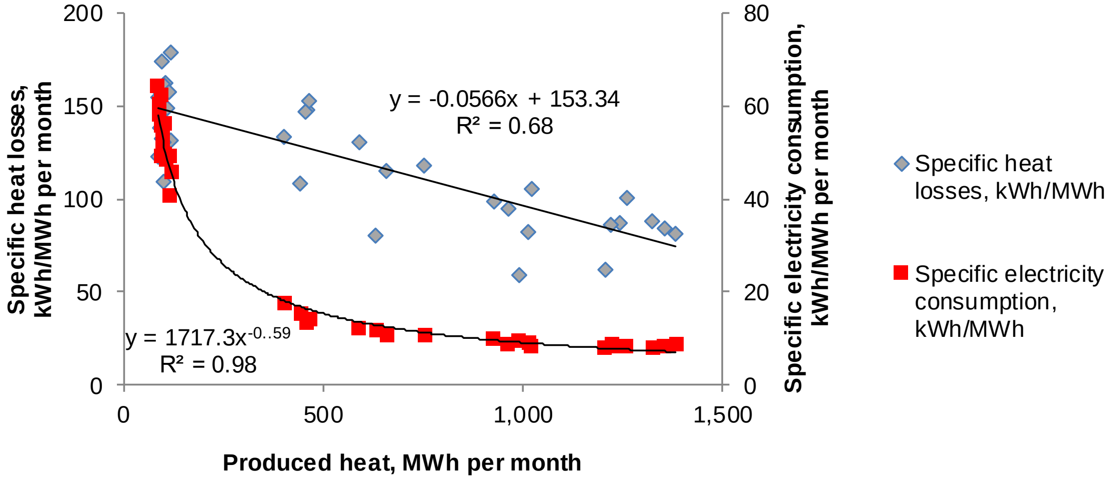

Figure 2: Regression analyses results

Specific electricity consumption varies in the wide range in the summer period from 40 to 64 kWh per MWh produced heat. Specific heat losses show a wide dispersion; it indicates the potential efficiency increase in studied boiler house. Operation data of the boiler house were further used to validate the proposed model.

3. Methodology

In order to evaluate various development scenarios of DH system and the possibility for a particular system to switch to 4GDH system, following methodology is proposed (see Figure 3).
In the first step it is necessary to evaluate the operation of DH for each of system's elements – heat source, distribution network and consumers' side. After historical operation data of current DH system was analyzed, various development scenarios were developed and simulated in order to converge current DH system to the 4GDH concept.

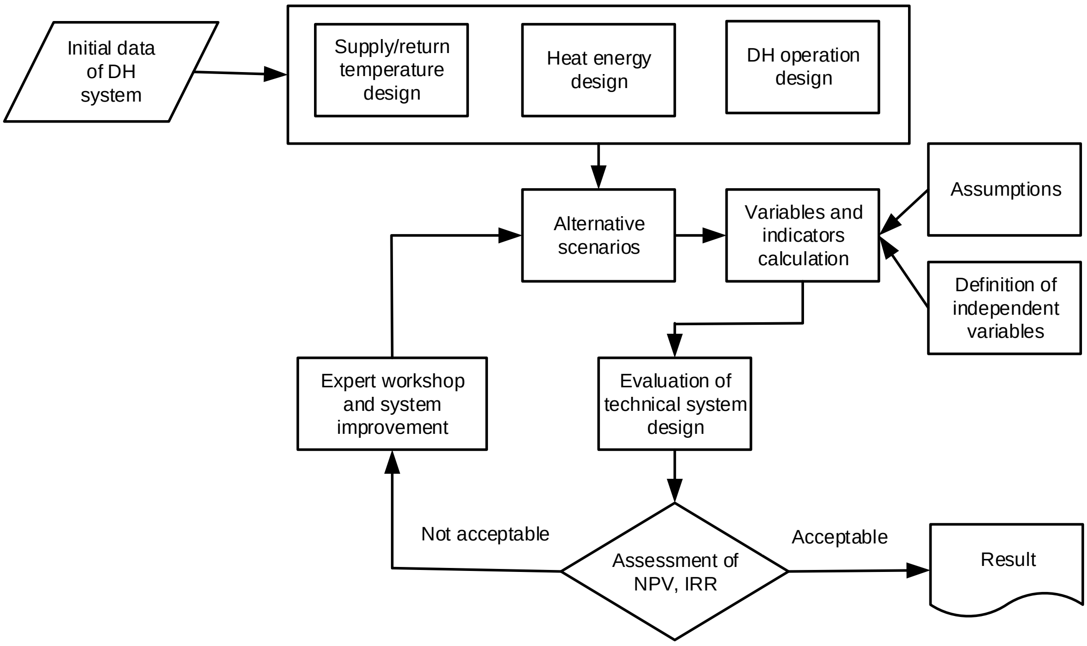

Figure 3: Algorithm of methodology

In the article three different scenarios are analyzed:

1. ExB (115/70); corresponds to an current situation where the existing system operates with the temperature regime 115/70 and heat consumers are existing buildings (ExB) with current heat energy consumption;
2. ExB (90/60); corresponds to decreased temperature regime 90/60, but energy consumption in existing buildings (ExB) does not change. This solution does not require additional investment in DH system;
3. EEB (60/30); corresponds to 4GDH concept, where a low temperature regime 60/30 is used, existing buildings are converted to energy efficient buildings (EEB) and biomass is used as the energy source. It is assumed that the renovation will take place only in residential apartment buildings and not in industrial buildings.
4. EEB (90/60) corresponds to decreased temperature regime 90/60 and existing buildings are converted to energy efficient buildings (EEB). This scenario is true in the situation, when only the demand for the heat energy is reduced, but the current DH system does not adapt to the changes.

The operation of DH system was modelled for each of these scenarios. In order to compare different alternatives indicators were chosen, they can be classified in three groups: technological, financial and energy efficiency indicators (Ziemele et al., 2014a). To determine heat transfer efficiency two main aspects are analyzed: heat losses in the network N_{los} (Wh/year), see Eq(1), and electricity consumption for heat distribution N_{ee} (Wh/year), see Eq(2).

$$N_{los} = t \sum_{n=1}^{j} q_{li} L_i \quad (1)$$

$$N_{ee} = tg\rho GH / \eta \quad (2)$$

Where q_{li} – linear heat losses (W/m), t – hours per time period (h), L_i – length of heat distribution network segment (m); j – total number of segments in piping network, H – total pressure drop (m), G – volume flow rate (m^3/s), g – gravitational acceleration (m/s^2), ρ –heat carrier density (kg/m^3), η – efficiency of pump (-).

The costs of heat energy distribution were calculated for all the scenarios by assuming constant electricity price 136 EUR/MWh and heat energy tariff 48.68 EUR/MWh.

Electricity consumption depends on the pressure losses in the system. For the hydraulic calculations of the DH system, pressure losses were modelled for each pipe segment and the path with the greatest pressure losses were determined, so called critical path (see Figure 4).

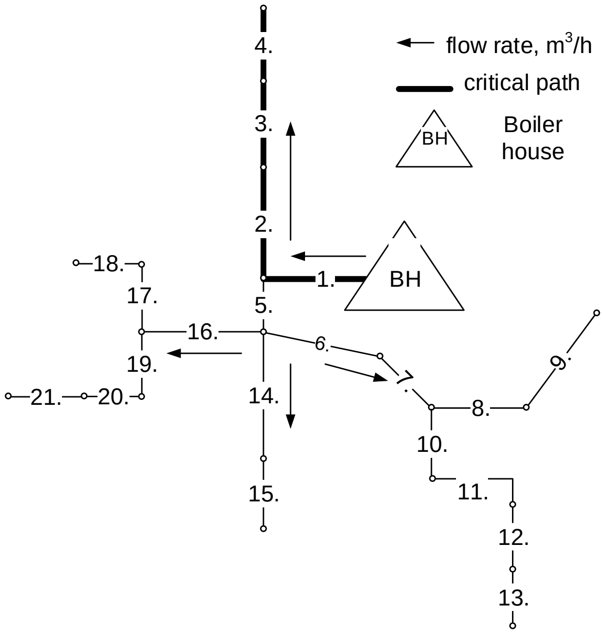

Figure 4: The scheme of heat energy distribution for hydraulic calculations

The capacity of heat source depends on the heat energy load at consumers and distribution losses. The transition to a low-temperature DH systems is closely related to buildings' renovation and consequential decrease in heat energy consumption; these measures requires investments in energy end-user. In this article it is assumed that the heat supply company will partly participate in the renovation process to ensure appropriate heaters in the case of a low temperature regime (60/30). To determine the investment efficiency of DH company the internal rate of return (IRR), discounted cash flow (NPV) and discounted payback time were calculated through energy efficiency measures. The assumed credit rate is 10 % per year at 50 % of the capital loan and inflation - 2.5 % per year.

4. Results

The amount of produced heat energy in 3rd EEB (60/30) scenario is reduced by 30 % due to buildings' renovation and corresponds to 4810 MWh per year. The specific heat energy consumption for space heating decreased, reaching 75 kWh/m^2 per year, after renovation measures. Corresponding costs of heat energy distribution for each scenario are given in Table 1.

Table 1: The costs of heat energy distribution

Scenario (temperature regime)	Total electricity consumption, MWh	Specific electricity consumption costs, EUR/MWh	Total heat losses, MWh	Specific heat losses costs, EUR/MWh	Specific distribution costs, EUR/MWh
ExB (115/70)	76	1.50	660	4.68	6.18
ExB (90/60)	78	1.54	648	4.59	6.13
EEB (60/30)	51	1.44	422	4.27	5.71
EEB (90/60)	78	2.20	648	6.56	8.75

The specific distribution costs in different scenarios are compared in Figure 5. The lowest specific distribution costs are in the 3rd EEB (60/30) scenario when a low temperature regime 60/30 is used. The resulting heat energy and electricity savings are small: heat losses are reduced by 7 % and electricity consumption by 6.8 % in EEB (60/30) scenario compering to the 2nd scenario ExB (90/60).

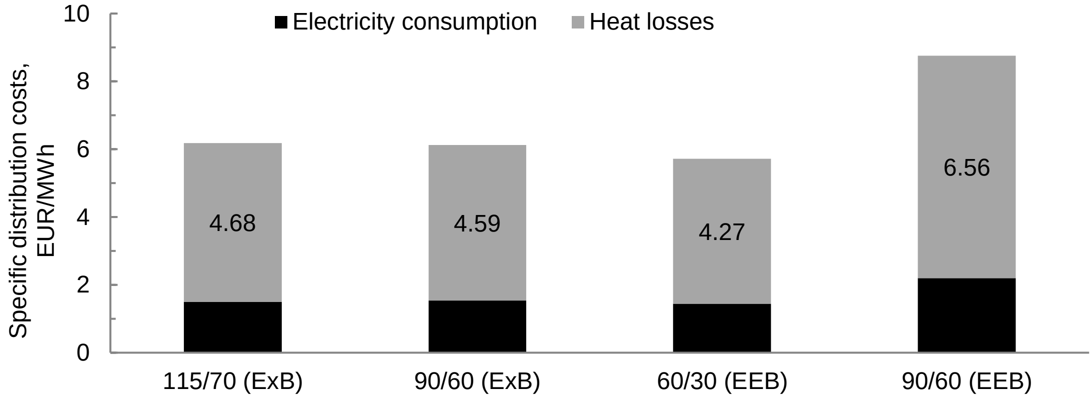

Figure 5: Specific distribution costs for different scenarios. Where 115/70, 90/60 and 60/30 are the temperature regimes at the DH network and ExB is existing building with current heat energy consumption and EEB is energy efficient building with reduced heat energy consumption.

It is necessary to take into account that in the 3rd EEB (60/30) scenario energy efficiency measures take place parallel to the temperature regime reduction. In opposite case, when only energy efficiency measures are introduced, but the temperature regime in DH network is not reduced, the specific distribution losses increase significantly. This scenario is illustrated as EEB (90/60) in Figure 5.

In the scenario EEB (90/60), both heat losses and electricity consumption increases by 53 % (compering to 60/30 (EEB) scenario) in the case temperature regime in DH system is not lowered, but energy efficient buildings are already introduced. Specific distribution costs (specific electricity consumption costs and specific heath losses costs together) at the temperature regime 115/70 and temperature regime 90/60 are similar, since DH supply and return water temperatures are comparable for those regimes, when using for the calculations the average mean temperature for space heating season of 0 °C for Latvian conditions.

The analysis showed that the existing infrastructure at DH substations – space heating and domestic hot water heat exchangers, regulators, heating pumps – are suitable for the use at the temperatures regime 90/60, but needs to be replaced in the case of the temperature regime 60/30.

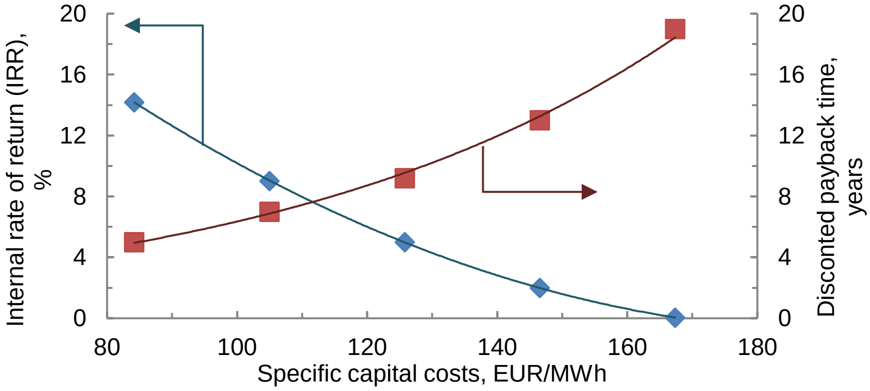

Figure 6: Financial analysis for the implementation of energy efficiency measures

From the one side, energy efficiency measures in apartment buildings are realized using private investments of building's residents or ESCO companies' funds, as well as financial support instruments from government. On the other side, energy efficiency measures in heat production units and distribution networks are realized using DH companies' funds and loans. Thus, the question arises, is it acceptable for DH companies to invest in the consumer side to adjust the heat emitting surfaces for operation at the low temperature regime; and how

much DH companies can afford to invest in raising energy efficiency in the properties of other owners. To analyze these aspects, the financial calculations were performed for 3rd EEB (60/30) scenario, see Figure 6.
The results shows that specific capital costs varies in the range from 84.2 to 167.4 EUR per MWh and discounted payback time from 5 to 19 years. The calculated IRR value varies from 14 % to 0.04 %.
The curves in Figure 6 represents the opportunity for DH companies to invest in energy efficiency measures while maintaining competitiveness. The measures that require capital costs up to 130 Euro/MWh are with relatively short discounted payback time (up to 10 years), therefore DH company could be interested in the implementation of these measures since overall system efficiency would be increased. Implementation of these measures will not lead to an additional heat energy costs for residents, because the heat tariff can remain constant (as for temperature regime 90/60) due to use of cheaper energy source , in this case study – biomass.

5. Conclusions

In this research the possibility to lower the temperature regime of DH network in existing built-up areas is analyzed. The evaluation of four scenarios is done using energy efficiency, technological and financial indicators.
Results show that switching to a lower temperature regime can reduce distribution costs and increase overall heat production efficiency. Therefore, in the situation when heat energy consumption in the existing buildings decreases, the current DH system (with high temperature regime) becomes inefficient, where specific distribution costs increases by more than 50 %.
In order to motivate the existing buildings and newly built areas to connect with DH system it is necessary to reduce the heat tariff; this target can be achieved by using cheaper energy source and/or by decreasing distribution costs. The results showed, that the calculated tariff of heat energy in energy efficient buildings and under a low temperature regime, in the case biomass is used as a fuel, is lower than for existing scenario.
This work concludes that 4GDH concept has a high potential in the future, because the implementation of this concept is closely related to the energy performance of buildings. With the development of energy efficient buildings and renovation of existing building stock, DH companies will be interested to lower the temperature regime in DH distribution network, so that the specific distribution costs for heat supply are reduced.

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