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Modelling of the District Heating System's Operation

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***Abstract – The* development of a district heating systems calculation model means improvement in the energy efficiency of a district heating system, which makes it possible to reduce the heat losses, thus positively affecting the tariffs on thermal energy.**

In this paper, a universal approach is considered, based on which the optimal flow and temperature conditions in a district heating system network could be calculated. The optimality is determined by the least operational costs. The developed calculation model has been tested on the Ludza district heating system based on the technical parameters of this system.

***Keywords* – district heating systems, heat losses, heat piping, boiler-house**

I. INTRODUCTION

The Latvian climate conditions impose particular requirements on the heat energy supply. This especially concerns district heating systems (DHS) − the dominant solution of supplying large cities with heat (~80% of the total number of heat energy users).

In the last 15 years the Latvian DHS have undergone substantial changes, which are associated with setting up a proper order as regards the end consumers. In the majority of buildings, automatic heat substations are installed in order to satisfy the demand for heating and hot water preparation. Actually, now we have a transition from one type of control to another, which makes it possible to optimize the heat network's operation. Earlier, the flow of thermal energy carriers via the heat pipelines was invariable, and qualitative control occurred at the heat source by varying the carrier's temperature. With the development of new technological possibilities, an opportunity has arisen to combine both approaches, thus switching to a quantitatively-qualitative control system. In this case, through heat ducts the heat carrier with variable direct pass temperature and adjustable flow will emerge. As a result, it will be possible to reach optimized hydraulic regimes of heat supply, with the circulating heat carrier flow and a reduction in its temperature; therefore, the heat energy consumption and losses will be smaller [2].

The developments described above will lead to an improvement in the energy efficiency of a DHS, which makes it possible to reduce the heat losses, thus positively affecting the tariffs on thermal energy.

In this paper, a universal approach is considered, based on which the optimal flow and temperature conditions in a DHS network could be calculated. The optimality is determined by the least operational costs using the large body of data accumulated by the Ludza Bio-Energy J/S Co on the operation of Ludza's DHS under different heat loads.

II. PROBLEM OF DHS OPERATION

The main weak point of a DHS, in comparison to a local or individual heat supply system, is the loss of heat at its transfer. This problem cannot be solved completely; therefore, the costs of heat losses are included in the end tariffs on heat (meant for the end users) [1]. From 1998 to 2004 the extent of heat losses in Ludza was reduced from ~30% (expressed in absolute units and equivalent to 4744 MWh/year) to 11.56%.

Based on the Ludza Bio-Energy J/S Co data on the heat energy produced and delivered to the end users of the Ludza city in the period 2004-2009, an annual section for the volume of consumed heat energy and losses is composed (shown in Fig. 1).

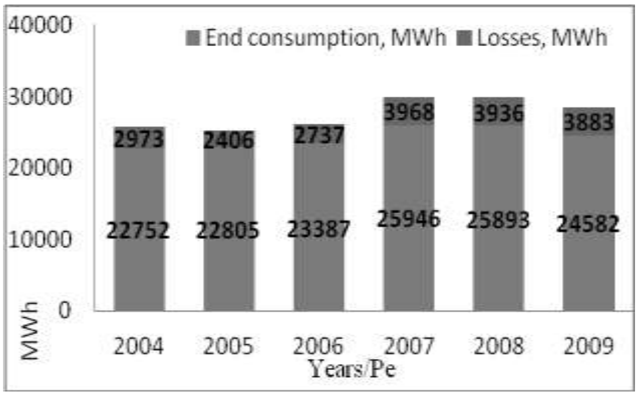

Fig.1. The heat energy end consumption and losses of the Ludza city DHS.

Analysis of the information presented in Fig.1 shows that the heat energy losses in the Ludza city heat duct(s) are still considerably high.

A heat transfer system can be considered efficient, if it meets the following conditions:

- the system has low heat energy losses − both from the surface of a heat duct (i.e. heat carrier's cooling in poorly insulated pipes) and due to heat carrier's leakages (in the cases of failures in the heat network and persistent leakages caused by wrong pipe laying) [5];
- the system has a definite temperature regime. It is of importance that the actual heat carrier's temperature is in compliance with the set temperature, so that the end user is provided with the high-quality service [3].

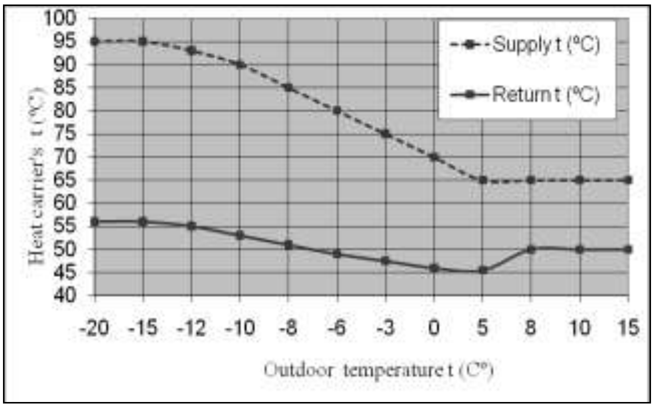

Fig.2. Factual temperature plot of the Ludza city heat network.

It is seen in Fig. 2 that for the peak hours (at -20 ºC), the Ludza city DHS should ensure the heat carrier's flow temperature of 95 ºC and the return temperature of 56 ºC, as well as a sufficient heat amount for all consumers of the Ludza Bio-Energy J/S Co. In summer an invariable temperature condition is maintained - the supply and return temperatures of 65 ºC and 50 ºC, respectively. For this, a quantitative control method is applied in the Ludza city heat network, with a built-in constant temperature (in Ludza DHS it is 65 ºC) but with a variable water flow. This makes it possible to reduce the number of circulation pumps and their load in hot weather, thus reducing electricity consumption.

Such a regulation system can be employed, if the consumer has an independent heating unit, which is insensitive to hydrostatic pressure. The variable water flow through exchangers is provided using the automatic temperature controllers which perform the following:

- non-stop monitoring of the heat carrier flow pressure; as a result, the optimal pressure condition is ensured also in all other DHS parts;
- maintenance of the pressure difference in the direct and return pass pipes, thus allowing optimal functioning of the heat supply, even to the most remote DHS sectors [4].

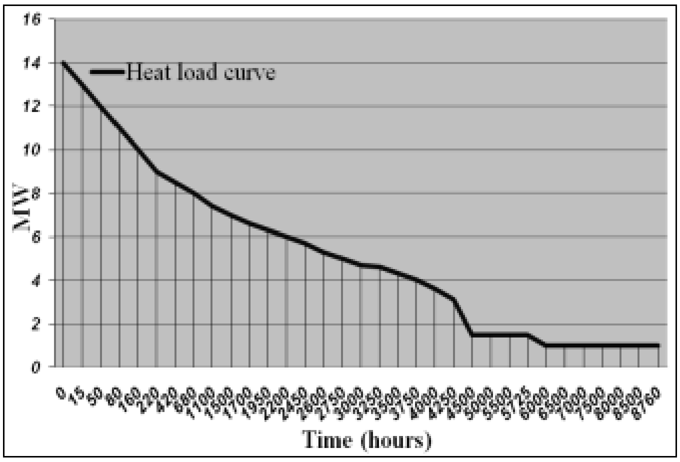

Fig. 3. Heat load schedule of the Ludza city DHS (2010).

The DHS functions in a very wide range − both in the daily and the yearly context. Therefore, the heat load and, respectively, the carrier's temperature should be forecasted both for the peak hours and for the summer load (in case it is demanded from a DHS). Figure 3 shows the yearly heat load schedule of the Ludza city DHS.

In Fig.3, the heat load and the demand for heat from the Ludza DHS in 2010 is shown by hours. As seen in Table 1, only 15 hours per year are needed for the peak load (over 13 MW), while for the summer load (~1MW) − 3035 h/year on average.

TABLE 1

DEMAND FOR HEAT IN THE LUDZA CITY BY HOURS AND THE RESPECTIVE HEAT PRODUCTION (2010)

Nr.	Heat demand (MW)	Working hours (h)	Produced heat (MWh)
1	13.0	15	195
2	10.0	145	1450
3	8.5	260	2220
4	6.8	1330	9013
5	6.0	450	2717
6	5.3	400	2109
7	4.2	1000	4228
8	3.2	600	1905
9	2.4	250	603
10	1.5	1275	1874
11	1.0	3035	3059
		8760	**29376**

In order to work out the heat piping specifications, the maximum load is taken (even if it is for 15 hours a year as in Ludza). This means that the chosen pipe diameter ideally fits the maximum load, while for the rest of the year it would be too large for the load needed. The solution to the problem is to install more powerful circulation pumps along the heating duct, which would compensate for a large diameter by higher pressure to ensure reliable heat supply to the end users even at the maximum load.

III. MODEL FOR OPTIMIZATION OF THE OPERATING PARAMETERS OF DHS NETWORK

A model for analyzing the operation of a DHS in order to optimize its parameters is illustrated in Fig. 4. The model comprises an output data module, a database module, a calculation module, and a module for the interpretation of results.

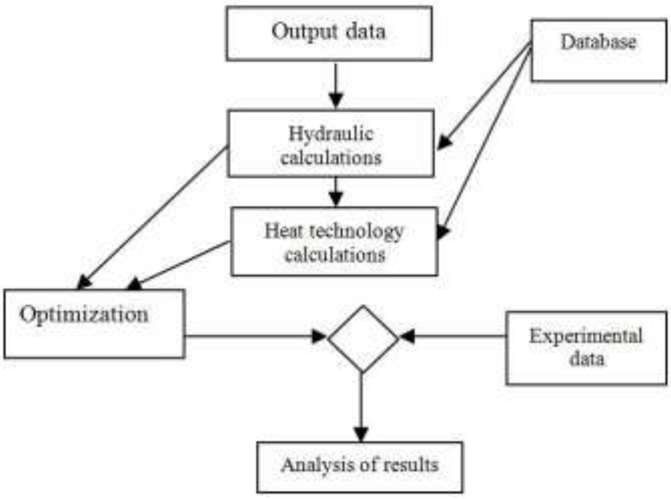

Fig. 4. Algorithm of the model for optimization of the DHS operating parameters.

IV. Output Data Module

For application of the mathematical model (worked out theoretically), the following data on DHS are required:

- temperature of the ground in summer, ^{o}C;
- temperature of the ground in winter, ^{o}C;
- tariff on the heat energy for users, Ls/MWh;
- tariff on electricity, Ls/MWh;
- length and diameter of pipes for a definite house and pipeline span, m;
- consumption of circulation pumps (for a particular pump model), MWh;
- load schedule;
- temperature plot.

V. Calculation Module

In our model, the calculation module includes equations for hydraulic calculations of piping and for the determination of heat losses.

The hydraulic calculations are performed by the method of specific pressure loss:

$$\Delta p = \frac{\lambda \cdot P_d}{d} \cdot l + \zeta P_d = R \cdot l + z = R \cdot l + \sum \xi \cdot \frac{v^2}{2 \cdot g} \qquad (1)$$

where

Δp is the pressure loss, Pa;
R is the linear pressure loss in a 1m long pipeline span, Pa;
λ is the coefficient of hydraulic resistance determined by the roughness of internal pipe surface and the flow regime;
d is the internal pipe diameter, m;
l is the length of a pipeline span, m;
P_d is the dynamic pressure, Pa;
z is the pressure losses in local resistances, Pa;
ζ is the coefficient of local resistances.

The formula for the heat carrier flow is:

$$G = \frac{3.6Q}{C_m \cdot (t_k - t_a)} \qquad (2)$$

where

G is expressed in kg/h
Q – the heat losses, kW;
C_m – the specific heat capacity of water (4.187 kJ/kg·K);
t_k– the supply temperature, ºC;
t_a – the return temperature, ºC.

The theoretical model comprises the worked out formula for calculation of the heat loss coefficient:

$$U = \frac{1}{(R_i + R_m + R_k + R_j + R_H)} \qquad (3)$$

where

U is expressed in W/(m·K);
R_i is the heat resistance of insulation, °C/W;
R_m is the heat resistance of the pipe with carrier flow, °C/W;
R_k is the heat resistance of pipe coating, °C/W;
R_j is the heat resistance of ground, °C/W;
R_H is the heat resistance of heat exchange between the supply and return pipes, °C/W.

The heat losses are proportional to a pipe's external surface, the heat transfer (transmission) coefficient, and the difference in temperatures of the heat carrier and surroundings.

The formula for the heat losses in a pair of the pipes looks as:

$$\varphi = U((t_1+t_2)-2t_g) \qquad (4)$$

where

φ – the heat losses per 1 m of a pipe pair, W/m;
U – the heat loss coefficient for a single pipe, W/m;
t_1 – the temperature of water in the supply pipe, °C;
t_2 – the temperature of water in the return pipe, °C;
t_g – the temperature of ground, °C.

The heat losses for the whole length of a pipe pair are determined by the formula:

$$Q_l = l \cdot \varphi / 1000 \qquad (5)$$

where

Q_l – the total heat losses in a pipe pair, kW;
l – the length of heat pipeline, m.

The model calculations of the electric (energy) power are performed by the formula:

$$Qc = \Delta p * G/1000 \qquad (6)$$

where

Q_c is the consumed power, kW;
G is the volume flow, m³/s

VI. Results of the Model Probation

The developed calculation model has been tested on the Ludza DHS based on the technical parameters of this system.

The mathematical modelling of the Ludza-city heat network was performed with the purpose of determining an optimal quantitatively-qualitative control system allowing the achievement of fewer heat transport costs. The model takes into account that Ludza's heat network was built 13 years ago, and is fitted for a new pipeline (based on the network in operation).

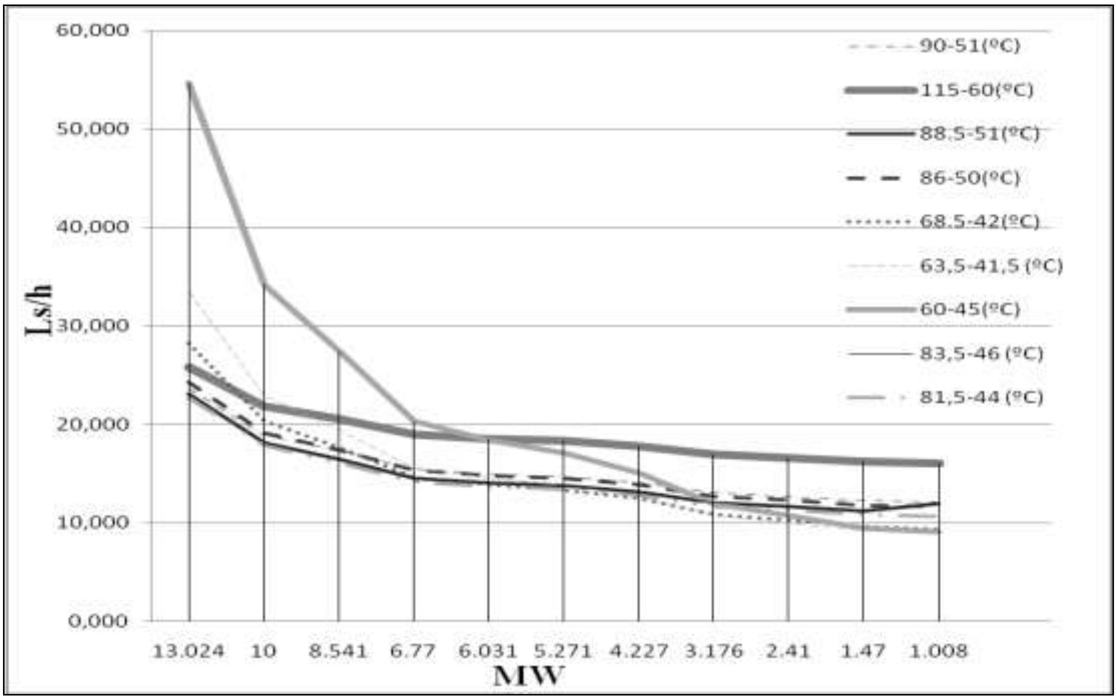

Fig. 5. Per hour costs of the Ludza-city district heating *vs.* corresponding power.

Fig. 5 indicates that the experiments based on the developed theoretical calculation model have been run using the 13-year old Ludza heating network's parameters (the supply and return temperatures). The aim was to find the optimal flow and temperature conditions under which the lowest operational costs are achieved.

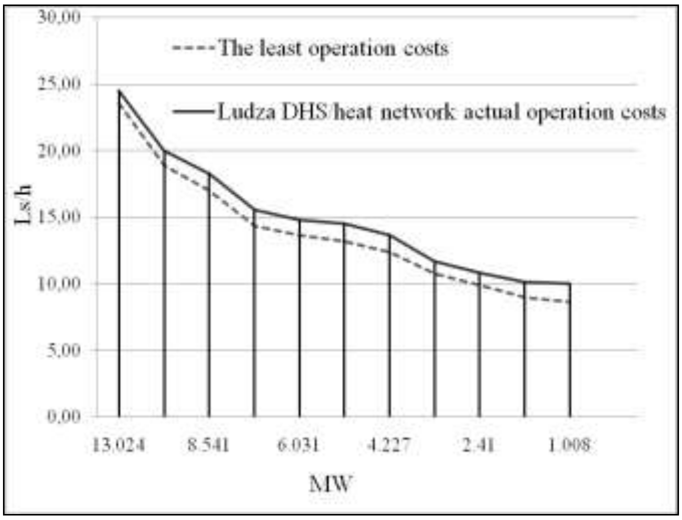

Fig. 6. Ludza DHS/heat network actual operation costs as compared with the lowest costs obtained by modelling.

As observed in Fig. 6, the Ludza DHS actual operation costs at the real temperature plot are close to the least operation costs calculated theoretically for the optimal temperature plot obtained in the process of work. The calculation model worked out for the Ludza heat supply system allows a reduction in the annual heat carrier transport cost by 12 333 Ls (i.e. 13 % of the total heat line operation costs).

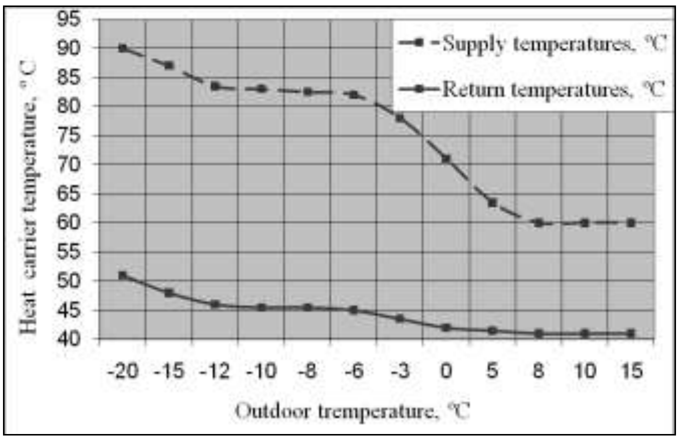

Fig. 7. The least cost temperature plot.

By analyzing the plots of Fig. 7 one can see that the temperature reduction should be considered as economically substantiated, since the money saved owing to a decrease in the heat losses exceeds the expenses of ensuring more intensive heat carrier circulation. The validity of the model is verified by a comparison of the real data collected in Ludza with experimental results that have been fitted to the operation of the Ludza DHS.

TABLE II

THEORETICALLY CALCULATED ANNUAL OPERATION COSTS OF THE LUDZA CITY HEAT NETWORK

Nr.	Power (MW)	Working hours (h)	Produced heat (MWh)	Supply temp. t1 (ºC)	Return temp. t2 (ºC)	Difference t1-t2=Δt (ºC)	Average outdoor temp. (ºC)	Cost (Ls/h)	Cost (Ls)
1	13.024	15	195	95	56	39	-20	24.492	367
2	10.000	145	1450	93.5	56	37.5	-14	19.980	2897
3	8.541	260	2221	91	55	36	-11	18.265	4748
4	6.777	1330	9013	76	48	28	-3,5	15.529	20653
5	6.039	450	2718	73.5	47	26.5	-1.6	14.775	6648
6	5.273	400	2109	72.5	47.5	25	-1	14.521	5808
7	4.228	1000	4228	68.5	46.5	22	2	13.643	13643
8	3.176	600	1906	68	46.5	21.5	2.3	11.690	7013
9	2.413	250	603	65	46	19	3.5	10.793	2698
10	1.470	1275	1874	65	48	17	6.5	10.114	12895
11	1.008	3035	3059	65	50	15	8	10,004	30362
	Total	**8760**	**29376**						**107737**

The data of Table 2 present the theoretical modelling results for the operational costs of the Ludza city heat network (both per hour and annual values) obtained in order to compare them with the actual heat carrier costs in this network.

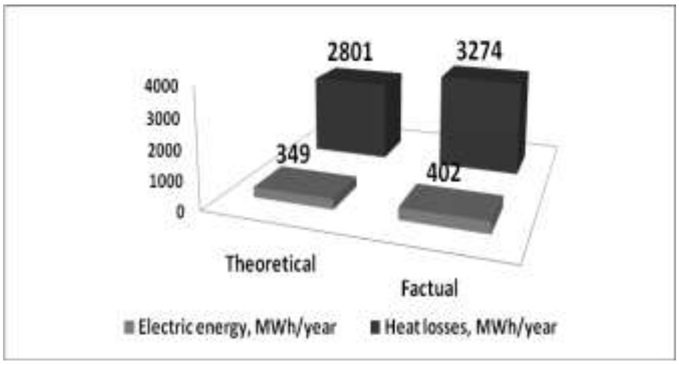

Fig. 8. Comparison of the theoretical and factual data on electricity consumption and heat losses.

According to the Ludza Bio-Energy J/S Co data on the heat energy produced and delivered to the end users of the city of Ludza, 29376 MWh were produced in 2010, while the losses were 3273.67 MWh, which was 11.1% of the total heat energy produced. At the same time, the established method gives the value of 2801.1 MWh/year for the heat losses, which is 9.5% of the total heat produced. The actual electricity consumption of the circulation pumps is 401.8 MWh/year, while the value obtained theoretically is 349.5 MWh/year. The total operational costs of Ludza's DHS network in 2010 were LVL 123 144, while those in compliance with the theoretical model were LVL 107 737.50.

VII. CONCLUSIONS

1. The testing of the model developed for optimization of the DHS operation has shown that the factual temperature plot is close to the optimal temperature plot calculated theoretically: in fact, the Ludza city DHS can operate with smaller expenses of LVL 12 333, which is 13 % of the total cost of the heat line operation.

2. The lowering of the temperature plot is economically justified, since the money saved owing to the reduced heat losses exceeds the expenses of ensuring more intensive heat carrier circulation. Simultaneously, this makes it possible to improve the efficiency of the DHS boiler-house operation as relates to the deep cooling of smoke gases.

3. In the long-term perspective, the calculations show that the increased heat losses in the 13-year old heat pipeline cause a 1.28 LVL/h increase in the operation cost on average (or the total of LVL 11 213 Ls a year).

VIII. REFERENCES

1. **Žīgurs, Ā., Cers, A.** Pilsētas siltumtīklu turpgaitas temperatūras samazināšanas ietekmes izpēte uz ekonomiskajiem rādītājiem. The Research Based on Economic Factors on Reduction of the Influence of Forwarding Temperatures in the Heat Systems of the City // RTU zinātniskie raksti. 6. sēr., Mašīnzinētne un transports. – 2. sēj. (2009), 1-100 lpp.
2. **Dalla Rosa, A., Li, H., Svendsen, S.** Method for optimal design of pipes for low-energy district heating, with focus on heat losses, Department of Civil Engineering, Technical University of Denmark, Brovej - 2011. - P. 2407-2418.
3. **Benonysson A., Bøhm B., Ravn, H. F.** Operational optimization in a district heating system, Energy Conversion and Management, Heating and Air Conditioning, Technical University of Denmark, DK-2800 Lyngby, Denmark – 2000. – P. 297-314

4. **Madsen, H., Sejling, K., Søgaard, H. T., Pallson, O.P.** On flow and supply temperature control in district heating systems, The Institute of Mathematical Statistics and Operations Research, The Technical University of Denmark, DK-2800 Lyngby, Denmark – 2003.- P. 613-620
5. **Keçebaş, A. , Alkan, M. A., Bayhan, M.** Thermo-economic analysis of pipe insulation for district heating piping systems, Mechanical Engineering Department, Architecture and Engineering Faculty, Süleyman Demirel University, Isparta, Turkey – 2011. – P. 3929-3937

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Ģirts Vīgants, Dagnija Blumberga. Centralizētās siltumapgādes sistēmas darbības modelēšana.
Latvijas klimatiskie apstākļi rada nepieciešamību pēc siltumenerģijas piegādes. Tas jo īpaši attiecas uz centralizēto siltumapgādes sistēmu, kas ir galvenais risinājums lielo pilsētu siltumapgādē (~80% no siltumenerģijas patērētājiem). Pēdējo 15 gadu laikā Latvijas centralizētā siltumapgādes sistēma ir piedzīvojusi izmaiņas, jo lielākajā daļā ēku ir uzstādītas apakšstacijas, lai apmierinātu pieprasījumu pēc siltumenerģijas un karstā ūdens. Principā tā ir pāreja no viena veida kontroles uz citu, kas ļauj optimizēt siltumtīklu darbību.
Izpētes ietvaros izstrādāts centralizētās siltumapgādes sistēmas aprēķina modelis, ar kuru var aprēķināt jebkuras pilsētas centralizētās siltumapgādes siltumtīklu optimālos plūsmu un temperatūru režīmus, pie kuriem ir zemākās ekspluatācijas izmaksas. Izstrādātais aprēķina modelis ir pārbaudīts uz Ludzas siltumapgādes sistēmas, ņemot vērā šīs siltumapgādes tehniskos parametrus. Ludzas pilsētas siltumtīklu matemātiskā modelēšana veikta ar mērķi noteikt optimālu kvantitatīvi – kvalitatīvo regulēšanas sistēmu, ņemot vērā, ka Ludzas pilsētas siltumtīkli tika izbūvēti pirms 13 gadiem, kā arī matemātiskais modelis tika pielāgots jaunas siltumtrases izbūvei uz Ludzas pilsētas siltumtīklu bāzes. Ludzas siltumapgādes sistēma darbināšana teorētiski dod iespēju siltumnesēja pārvades izmaksas gadā samazināt par 13 % no kopējām siltumtrases ekspluatācijas izmaksām. Temperatūras grafika pazemināšana uzskatāma par ekonomiski pamatotu pasākumu, jo naudas līdzekļi, kas tiek ietaupīti līdz ar siltuma zudumu samazinājumu, pārsniedz izdevumus, kas radušies intensīvākas siltumnesēja cirkulācijas nodrošināšanai. Tas vienlaikus paver iespējas sistēmas efektivitātes paaugstināšanai dūmgāzu dziļai dzesēšanai siltumapgādes sistēmas katlumājā.