THE DEPENDENCE OF QUALITY AND EFFICIENCY OF DISTRICT HEATING ON THE TYPE OF LOAD REGULATION

CENTRALIZĒTĀS SILTUMAPGĀDES ENERGOEFEKTIVITĀTES ATKARĪBA NO SLODZES REGULĒSANAS VEIDA

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Keywords: *district heating, temperature graphs, economic parameters, quantitative and qualitative regulation*

Abstract. The dynamic properties of district heating (DH) systems includes water flow rate and heat propagation from heat production plant to consumers. Reduced heating water flow rate was estimated in Riga city district heating system net during heating season of year 2008/2009. Such decrease in flow rate can be explained with reducing of heat losses of buildings as well as more economical usage of heat energy. The objective of this paper is to investigate the possibility of successful heat transition from DH plant "Vecmīlgrāvis" by decreasing of the supply temperature of water from the temperature graph 130/70 °C to the temperature graph 115/70 °C. At the same time, the reliability and quality of the heat distribution to the customers must be kept unchanged. The flow ratio depends on the heat demand and the temperature of the hot water supply. With the goal of keeping the output temperature from DH plant as low as possible, it is necessary to determine the upper limit for the flow on the DH network, which depends on pipes diameters, technical condition, pumps etc. Operational data from the DH plant "Vecmīlgrāvis" were used to estimate theoretical calculations in this paper.

Introduction

Nowadays, when market conditions define levels of production, offer and demand, it is highly important to secure the supply of the consumers with the heat power of high quality. The supply of customers with necessary heat in needed quality and quantity is a complicated task, which is closely related to variable heat loads in time, a big district heating system inertia and with the necessity to transport energy via long and ramified heating grid. Additional complication produces a diversified heat load of the consumers: heat, ventilation and hot water supply. These types of heat load vary depending on the season and day schedules, as well as demand for heat with different potential. The heat and ventilation loads vary depending on season and the ambient air temperatures, they rise if the air temperature drops and vice versa. But the hot water load can be described as a rather constant value during the whole year; it does not depend much on the air temperature, but significantly fluctuate during the day.

To solve the equation of the effective heat supply of the consumers, including the division of heat load among them, the regulation of the heat load is applied in the heat supply system.

One of the most important tasks, developing a complex scheme of the elaboration of heat sources and the heating grid, is to identify the necessary heat sources and heat loads, as well as the distribution between them. The technical and economical parameters of the grids and sources are in dependence from the chosen distribution of loads, although, the possibilities of development, which make possible a future attraction of new consumers to the system, makes a significant impact too. The main aim of different version DHS (district heating system) development is [5]:

- To secure the heat supply of existing consumers and the possibility to connect new, already specified in the regulations, heat loads, taking in account the heat loads of other potential construction sites and territories;
- To maximize the load of the existing effective generating units, especially the cogeneration power units and in case of extra necessity to justify technically and economically the installation of new heat sources or power units;
- To guarantee the security of heat supply;
- To guarantee economically justified costs of heat supply.

The next important step after the definition of the total heat loads is to allocate them among heat sources and consumers. The allocation process is rather complicated, because there must be taken several limiting factors in account, such as:

- The configuration of heating grids, their technical conditions and operating parameters, as well as real possibilities to add new branches of grids or the renovation of existing ones;
- The loads of heat sources and their descriptions, development possibilities, taking in account the conditions of load reservation for the heat supply security;

- The temperature graph of the heat carrier;
- The geographical distribution and location of the existing and newly added consumers.

Qualitative and quantitative regulation methods of the district heating system

Actual economical development motivates solutions of heat supply with lowered heat carrier parameters, when the quantitative or quantitatively-qualitative heat load regulation is used. The advantages and disadvantages of these methods are listed in Table 1.

The further increase of the efficiency of the district heating system is possible with a significant expansion of the usage and almost a total replacement of the modest qualitative regulation method by quantitative and quantitative-qualitative regulation methods. One of the most important factors, which leads to transition to the quantitative regulation of the heat load of the heating system is the possibility to obtain better variable indicators of water consumption. It is reasonable using only quantitative and quantitative-qualitative regulation methods [1].

The current qualitative regulation method emphasizes the importance of the temperature graph. The analyses of the impact of the method on the efficiency of the heating system is described in the example below, where a proposal to go for a transition of DH plant „Vecmīlgrāvis" form the Temperature graph 130/70 °C (with the max limitation 120 °C) to the Temperature graph 115/70 °C is made.

The comparison of costs for the old and new (existing and potential) regulation methods is given in the calculus. If the temperatures graph of the heating system changes, the variable part of the operational costs is:

1. The change of consumption of electricity needed to transfer a heat carrier.
2. Heat loses in the heating grid system.

Table 1

1. tabula

The advantages and disadvantages of the qualitative and quantitative regulation methods of the district heating system with with an independent connection of consumers

Kvalitatīvās un kvantitatīvās režīma regulēšanas metodes priekšrocības un trūkumi centralizētās siltumapgādes sistēmās ar atdalīto patērētāju pieslēgumu

The heat supply regulation method	
Qualitative regulation	Quantitative regulation
Advantages 1. Reduces heat losses in the heating grid. 2. Stable hydraulic flow in the heating grid. 3. Stable hydraulic regimen in the heating sources. 4. Increases efficiency of district heating boilers. 5. A slightly higher operating resource of installations and better labour safety conditions, due to lower average T_1. Disadvantages 1. A higher consumption of electricity for pumping of a heat carrier. 2. The personnel of the dispatcher centre must follow the weather forecasts and adopt T_1 instantly. .	Advantages 1. A lower consumption of electricity for pumping of heat carrier. 2. The possibility to make the work of the dispatch centre personnel easier. Disadvantages 1. Enlarged heat losses in the grid. 2. The variable hydraulic flows of the heating network and in heat sources. 3. Reduced efficiency of district heating boilers. 4. A slightly lowered operating resource of installations and more hazard working conditions for personnel due to a higher average T_1.
The parameters, which are almost independent from the regulation method, in the case , when the value of T_1 is never lower than the one defined from the temperature graph: 1. Heat load. 2. The temperature inside the customers' rooms. 3. The temperature of hot water. 4. The accuracy of the internal room and hot water temperature regulation. 5. The costs for District heating feed water makeup. 6. The pipeline corrosion rate.	

The Calculus of the Electricity Consumption Needed to Transfer a Heat Carrier

The electricity consumption needed to transfer a heat carrier, MWh:

$$E = a \cdot G \cdot H \cdot n / \eta \,, \qquad (1)$$

where

a – transformation coefficient - $2{,}7248 \cdot 10^{-6}$;

G - water flow in the grid, t/h;

H - the pressure difference of grid pumps, mWC;

n - the amount of operating hours of the grid pumps during one heating season;

η - the efficiency of the pump installations (the efficiency coefficient of the pump η_p the factum with the efficiency of the electromotor η_{el}).

Comparing the cases of different parameters of grid water, MWh:

$$\Delta E = E_2 - E_1 = (G_2 \cdot H_2 - G_1 \cdot H_1) \cdot a \cdot n / \eta \qquad (2)$$

(adopting that the efficiency coefficient of pump installations does not change in case of real flow and pressure difference range).

Considering DH plant "Vecmīlgrāvis" heat loses in the heating grid as relatively low, it is acceptable, after the necessary hydraulic calculations, to have a flow rate enlargement of 30% without any kind of replacement of pipelines and any increase of the direct flow pressure P1 in the heat sources. Thereby, taking in account the change of hydraulic losses in the internal scheme of the heat loses, the equation $H_1 = H_2$ becomes relevant.

Then, MWh:

$$\Delta E = E_2 - E_1 = (G_2 - G_1) H \cdot a \cdot n / \eta \qquad (3)$$

or

$$\Delta E = E_2 - E_1 = (k-1) \cdot G_1 \cdot H \cdot a \cdot n / \eta \,, \qquad (4)$$

where

$k = G_2 / G_1$ - the coefficient of the alteration of the consumption of the grid water, in case of transition form the existing temperature graph to the potential one.

Taking in account that the heat source power given to the grid does not depend on the temperature graph:

$$G_1 \cdot \Delta T_1 = G_2 \cdot \Delta T_2 \,, \qquad (5)$$

where

ΔT_1 and ΔT_2 - the temperature difference on the outlet of the heating source applying different temperature graphs;

in such case

$$G_2 / G_1 = \Delta T_1 / \Delta T_2 \qquad (6)$$

and

$$k = \Delta T_1 / \Delta T_2 \,. \qquad (7)$$

The amount of change of grid water, in case of transition form the existing temperature graph to the potential one, is a depending value form the change of difference of direct flow temperature T_1 and return water temperature T_2. This value is not constant; it depends on the ambient temperature T_a. Because of that circumstance, the alteration coefficient of the grid water consumption during the heating season, in case of transition form the existing temperature graph to the potential one, can be calculated as an average weighted value, taking in account the duration of different ambient temperature values [6].

Table 2

2. tabula

The results of the calculus of the alteration of water consumption coefficient in DH plant "Vecmīlgrāvis"

SC "Vecmīlgrāvis" tīkla ūdens patēriņa izmaiņas koeficienta aprēķina rezultāti

T_a range	Hours	DH plant „Vecmīlgrāvis”						$k = \frac{\Delta T^{130-70}}{\Delta T^{115-70}}$
		Existing graph 130-70°C			Potential graph 115-70°C			
	n	T_1^{130-70}	T_2^{130-70}	ΔT^{130-70}	T_1^{115-70}	T_2^{115-70}	ΔT^{115-70}	
°C		°C	°C	°C	°C	°C	°C	
> + 5	998	66	39	27	65	39	26	1,039
0 + +5	1816	70	41	29	64	42	22	1,290

-5 + 0	1202	85	46	39	75	47	28	1,367
-10 + -5	553	99	52	47	87	53	34	1,373
-15+ -10	260	112	57	55	98	58	40	1,377
-20+ -15	77	120	59	61	109	60	49	1,247
<-20	14	120	59	61	115	60	55	1,110

Notes:

1. T_1^{130-70} and T_1^{115-70} after the confirmed temperature graph.
2. T_2^{130-70} in accordance to 2006./2007 heating season actual return water temperature statistical data.
3. T_2^{115-70} obtained values.

Average weighted in Table 2:

$$\bar{k} = \sum n \cdot k / \sum n = 1{,}271 \qquad (8)$$

The average flow during the heating season: 537 t/h.
Average pressure difference in grid pipes: 65 mWC.

The duration of the heating season: 4920 h.

In accordance with formula (4) the alteration of the electricity consumption is, MWh:

$$\Delta E = (1{,}271 - 1) \cdot 537 \cdot 65 \cdot \cdot 2{,}7248 \cdot 10^{-6} / 0{,}8 = 158{,}5$$

There is no duration of different ambient temperature values in accordance with Latvian construction code LBN 003-01 "Construction Climate” [2] that is the reason to use data from [3].

The change of the amount of the heat carrier during the day can be observed in the charts representing the results of the experiments at DH plant „Vecmīlgrāvis” (figures 1 and 2).

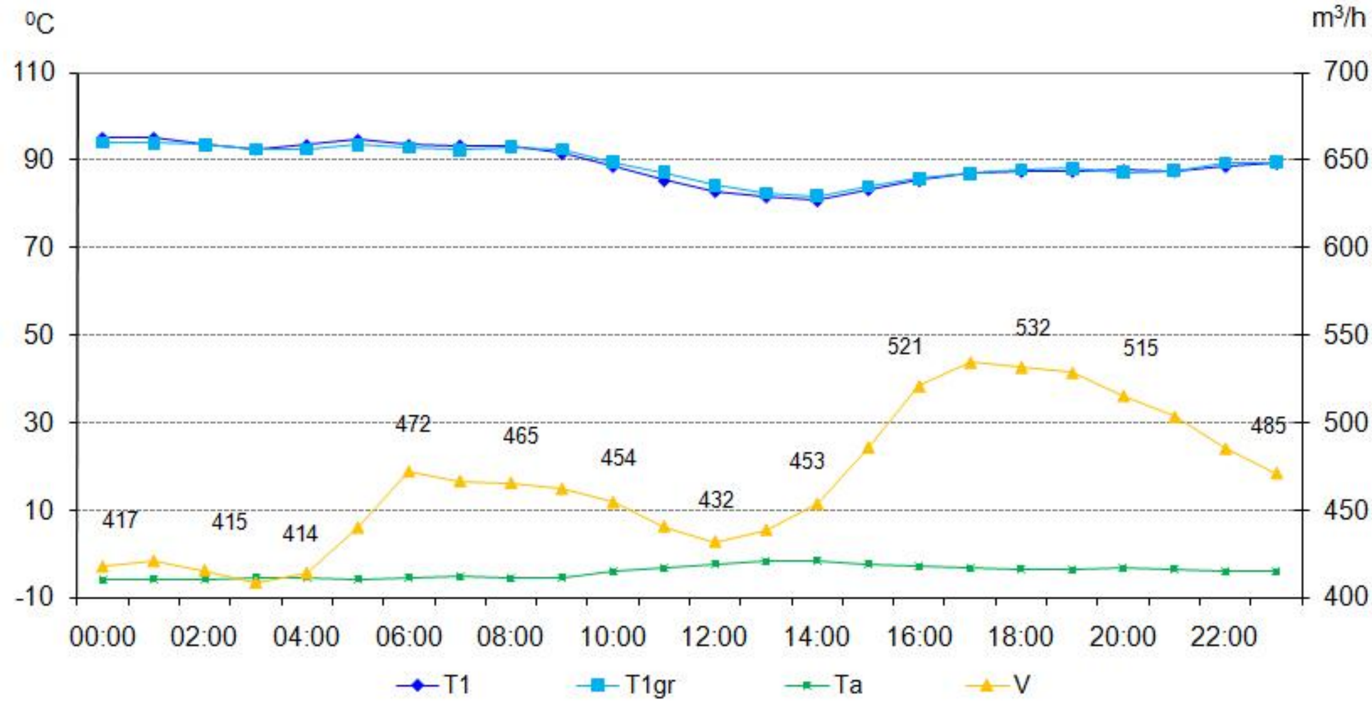

Fig.1 The Temperature Graph and Feedtrough of the Heat Carrier at the DH plant “Vecmīlgrāvis” by 17.02.2009 (T_a=-3,8 °C, T_1-T_{1gr}=1.1 °C): T_1 – Real Temperature of Heat Carrier, °C; T_{1gr} – Theoretical Temperature of Heat Carrier on the Temperature Graph, °C; T_a – Ambient Temperature, °C; V – Flow of Heat Carrier, m^3/h.

1.att. SC “Vecmīlgrāvis” siltumnesēja temperatūras un caurplūdes grafiks par 17.02.2009 (T_a=-3,8 °C, T_1-T_{1gr}=1.1 °C): T_1 – siltumnesēja faktiskā temperatūra, °C; T_{1gr} – siltumnesēja teorētiskā temperatūra pēc temperatūras grafika, °C; T_a – ārēja gaisa temperatūra, °C; V – siltumnesēja patēriņš, m^3/h.

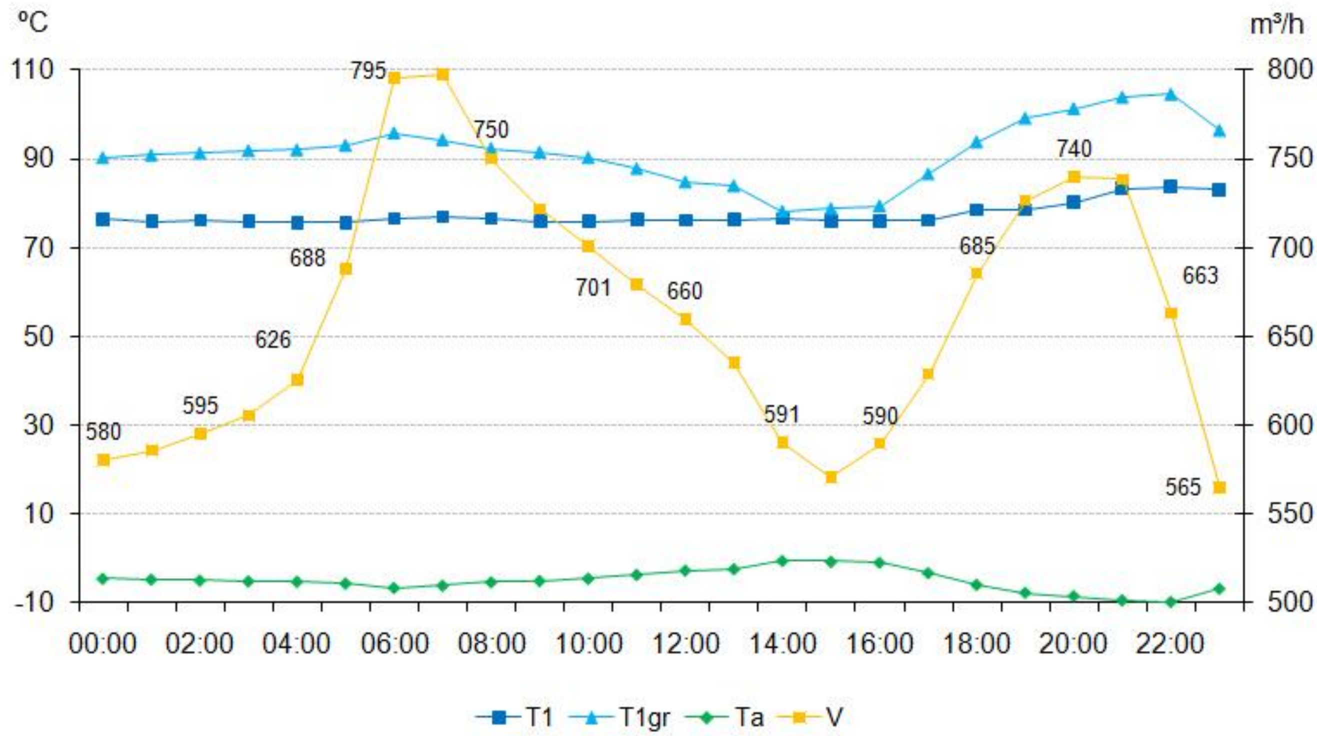

Fig.1 The Temperature Graph and Feedtrough of the Heat Carrier at the DH plant "Vecmīlgrāvis" by 19.02.2009 (T_a=-4,2 °C, T_1-T_{1gr}=11.8 °C): T_1 – Real Temperature of Heat Carrier, °C; T_{1gr} – Theoretical Temperature of Heat Carrier on the Temperature Graph, °C; T_a – Ambient Temperature, °C; V – Flow of Heat Carrier, m^3/h.
1.att.SC "Vecmīlgrāvis" siltumnesēja temperatūras un caurplūdes grafiks par 19.02.2009 (T_a=-4,2 °C, T_1-T_{1gr}=11.8 °C) T_1 – siltumnesēja faktiskā temperatūra, °C; T_{1gr} – siltumnesēja teorētiskā temperatūra pēc temperatūras grafika, °C; T_a – ārēja gaisa temperatūra, °C; V – siltumnesēja patēriņš, m^3/h.

The Calculus of Heat Losses

The operational heat loses Q_{loses} consist of two parts: 1) loses via pipeline surface and armature, Q^1; 2) loses with water leakage from heating grids, Q^2.

The second component, if other conditions are equal, does not change in both cases.

The calculus of loses via pipeline surface should be made for both versions separately [4] for underground and over ground pipes:

- for underground pipelines:

$$Q^1_{up2} = Q^1_{up1} \cdot \frac{T_{1.2} + T_{2.2} - 2 \cdot t_{gr.2}}{T_{1.1} + T_{2.1} - 2 \cdot t_{gr.1}} \tag{9}$$

- for supply pipe of above ground pipelines:

$$Q^1_{d2} = Q^1_{d1} \cdot (T_{1.2} + T_{a2}) / (T_{1.1} + T_{a1}) \tag{10}$$

- for return pipeline of above ground installation:

$$Q^1_{r2} = Q^1_{r1} \cdot (T_{2.2} + T_{a2}) / (T_{2.1} + T_{a1}) \tag{11}$$

where

Q^1_{up1} and $Q^1_{up.2}$ - heat loses from the underground pipelines for different temperature graphs, MWh;

Q^1_{d1} and Q^1_{d2} - heat loses from the above ground direct flow pipelines for different temperature graphs, MWh;

Q^1_{r1} and Q^1_{r2} - heat loses form the return pipelines for different temperature graphs, MWh;

$T_{1.1}$ and $T_{1.2}$ – the temperatures of the water in the direct pipeline for different temperature graphs, °C;

$T_{2.1}$ and $T_{2.2}$ – the temperatures of the water in the return pipeline for different temperature graphs, °C;

$t_{gr.1} = t_{gr.2}$ – soil temperature, °C;

$T_{a1} = T_{a2}$ – ambient temperature, °C.

Comparing different options with different temperature graphs, MWh:

$$\Delta Q^1 = Q_2^1 - Q_1^1 \qquad (12)$$

Taking in account the circumstance that the above ground pipelines of the DH plant "Vecmīlgrāvis" are relatively short, the calculus can be made considering the formula (9), or, MWh:

$$\Delta Q^1 = k \cdot Q_1^1 - Q_1^1 \qquad (13)$$

where

$k^1 = \dfrac{T_{1.2} + T_{2.2} - 2 \cdot t_{gr.2}}{T_{1.1} + T_{2.1} - t_{gr.1}}$ - the coefficient of heat loses alterations, in case of transition from the existing temperature graph to the potential one.

The amount of change of grid water, in case of transition form the existing temperature graph to the potential one, is a depending value form the change of difference of supply line temperature T_1 and return water temperature T_2. This value is not constant; it depends on the ambient temperature T_a. Because of that circumstance, the alteration coefficient of the grid water consumption during the heating season, in case of transition form the existing temperature graph to the potential one, can be calculated as an average weighted value, taking in account the duration of different ambient temperature values [6].

The actual temperatures and the T_1 according to the graph 130/70 °C and the graph 115/70 °C are presented in figure 3.

There is no soil temperature in accordance with Latvian construction code LBN 003-01 "Construction Climate" [2], that is the reason to use data from [3], for the period "October - April" 0,8 m deep $t_{gr.1} = t_{gr.2}$=4,1 °C

Table 3
3. tabula

The results of the calculus of heat loses for DH plant "Vecmīlgrāvis"
SC "Vecmīlgrāvis" siltuma zudumu koeficienta aprēķinu rezultāti

T_a range	Hours	DH plant "Vecmīlgrāvis"				
		Existing graph 130-70°C		Potential graph 115-70 °C		k^1
	n	T_1^{130-70}	T_2^{130-70}	ΔT^{130-70}	T_2^{115-70}	
°C		°C	°C	°C	°C	
> + 5	998	66	39	65	39	0,9897
0 + +5	1816	70	41	64	42	0,9558
-5 + 0	1202	85	46	75	47	0,9327
-10+ -5	553	99	52	87	53	0,9242
-15+ -10	260	112	57	98	58	0,9175
-20+ -15	77	120	59	109	60	0,9416
<-20	14	120	59	115	60	0,9766

Notes:

1. T_1^{130-70} and T_1^{115-70} in accordance with temperature graph.
2. T_2^{130-70} 2006/2007 heating season actual return water temperature statistic data.
3. T_2^{115-70} obtained temperature values.

Average weighted in Table 3:

$$\bar{k} = \sum n \cdot k / \sum n = 0{,}9481 \qquad (14)$$

In accordance with the formula (13), taking in account the loses from the pipeline surface and armature, the significant impact has the alteration of heat loses, MWh:

$$\Delta Q^1 = 0{,}9481 \cdot 8311{,}1 - 8311{,}1 = -431{,}0$$

The existing heat loses (8311,1 MWh) are recalculated for the period "November to March" to the actual average heat loses for the considered heating season duration of 4920 h.

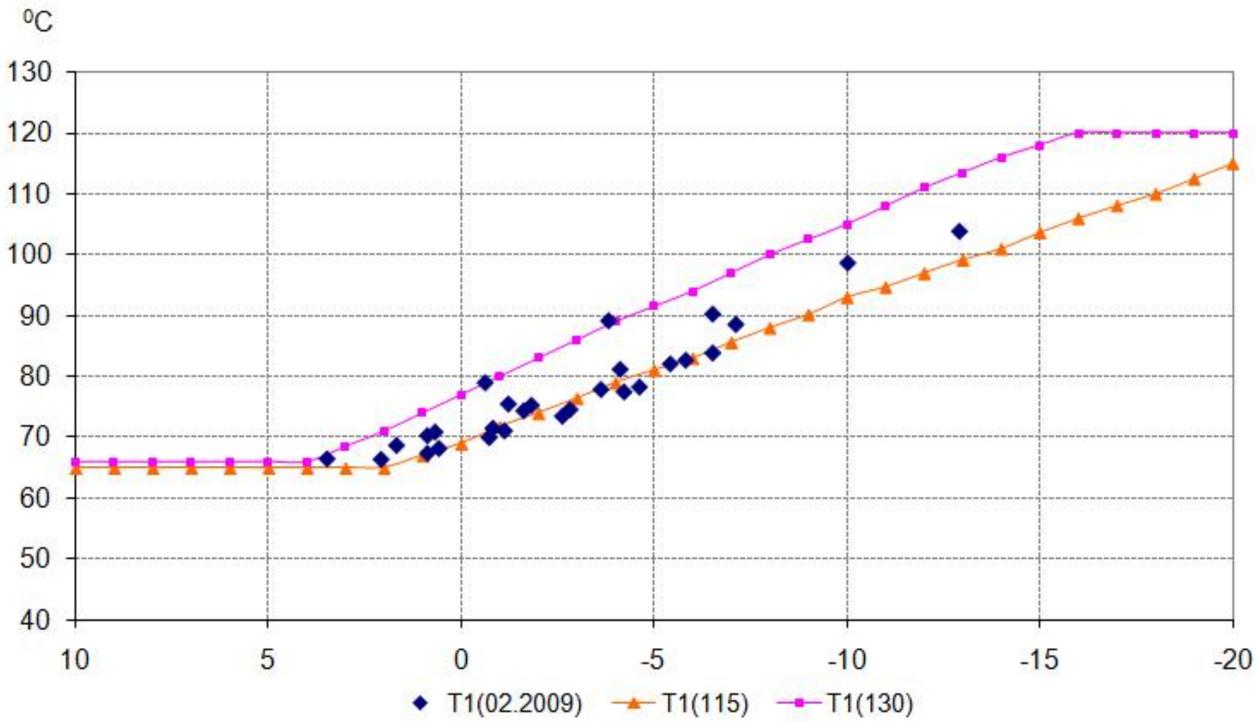

Fig.3 The Consideration of the Temperature Graph of the Heat Carrier at the DH plant "Vecmīlgrāvis" in February 2009 Regarding the Temperature Graphs 130/70 °C un 115/70 °C: T_1 (02.2009) – Real Temperature of Heat Carrier in February 2009; T_1 (115) – Theoretical Temperature of Heat Carrier on the Temperature Graph 115/70 °C; T_1 (130) – Theoretical Temperature of Heat Carrier on the Temperature Graph 130/70 °C

3.att. SC "Vecmīlgrāvis" siltumnesēja temperatūras grafika ievērošana 2009. gada februārī attiecībā pret temperatūras grafikiem 130/70 °C un 115/70 °C: T_1 (02.2009) – siltumnesēja faktiskā temperatūra 2009. gada februārī; T_1 (115) – siltumnesēja teorētiskā temperatūra pie temperatūras grafika 115/70 °C; T_1 (130) – siltumnesēja teorētiskā temperatūra pie temperatūras grafika 130/70 °C

The Results of the Calculus

In case of transition of the DH plant "Vecmīlgrāvis" from the temperature graph no 130/70 °C (with max limitation of 120 °C) to the temperature graph 115/70 °C, in accordance with the calculus, the flow rate in the grid will be enlarged by ~30% and the reduction of heat loses in the grid in comparison with the existing one will be about ~ 5%.

In accordance with the boiler house (BH) "Gobas 33a" and BH "Keramikas 2a" operational experience, heat substation installations are capable to ensure the supply of the consumers with necessary parameters after the transition to the lowered temperature graph.

Table 4

4. tabula

The results of transition from the temperature graph 130/70 °C to the temperature graph 115/70 °C

Pārejas no temperatūras grafika 130/70 °C uz temperatūras grafiku 115/70 °C rezultāti

The enlargement of the electricity consumption by the grid pumps	The reduction of heat loses
MWh / heating season	MWh / heating season
158,5	431,0

Conclusions

For the successful transition of DH plant "Vecmīlgrāvis" from the temperature graph 130/70 °C (with max limitation of 120 °C) to the temperature graph 115/70 °C, the process must be evaluated from the DHP and the heating grid installations operation (operating duration, security, etc.) point of view, as well as an economical calculus must be additionally completed.

Completing an economical calculus for such type of transition the following parameters should be taken in account – the prime costs of produced heat, the prime costs of consumed electricity and the condition, that consumption of electricity by grid pumps cannot be called as a total loss. Any kind of pump, including grid pumps, the biggest part of consumed electricity converts to heat energy (~90 %). It is transferred to the water in the system, which makes possible to call the pumps some kind of electrical boiler installation.

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Centralizētas siltumapgādes energoefektivitātes atkarība no slodzes regulēšanas veida

Centralizētās siltumapgādes sistēmu dinamiskās īpašības ietver sevī siltumnesēja caurplūdi un siltuma izplatīšanu no siltumavota līdz patērētajiem. Salīdzinājumā ar iepriekšējām apkures sezonām, Rīgas pilsētas siltumtīklu ekspluatācijas laikā 2008/2009 gada sezonā tika novērota samazināta siltumnesēja caurplūde siltumtīklos darba režīmos ar iepriekš pieņemtajiem temperatūras grafikiem. Šāda caurplūdes samazināšanās varētu būt izskaidrojama ar ēku siltuma zudumu samazināšanos, kā arī ar ekonomiskāku siltumenerģijas patēriņu. Ņemot vērā augstāk minētos apstākļus, tika veikts eksperiments ar mērķi izpētīt sekmīgas siltuma pārneses iespējamību no SC „Vecmīlgrāvis" ar pazeminātu turpgaitas temperatūru, pārejot no temperatūras grafika 130/70 °C uz 115/70 °C. Šī pāreja nedrīkst pazemināt patērētājam piegādātās siltumenerģijas drošumu un kvalitāti. Siltumnesēja caurplūde (patēriņš) ir atkarīgs no patērētāju siltumslodzes un siltumtīkla ūdens temperatūras. Lai uzturētu izejas temperatūru no siltumavota pie iespējas zemākā līmenī, nepieciešams noskaidrot siltumnesēja caurplūdes augstāko robežu, kas savukārt ir atkarīga no cauruļvadu diametriem, tehniskā stāvokļa un siltumtīklu sūkņu izvēles. Teorētisko aprēķinu veikšanai izmantoti SC „Vecmīlgrāvis" ekspluatācijas tehniski – ekonomiskie dati.

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Энергоэффективность централизованного теплоснабжения в зависимости от типа регулирования тепловой нагрузки

Динамические свойства централизованного теплоснабжения включают в себя поток теплоносителя и распространения тепла от теплоисточника до потребителя. Во время эксплуатации теплосетей города Риги в отопительный период 2008/2009, по сравнению с предидущими периодами, было замечено уменьшенние расхода теплоносителя при соблюдении установленного температурного графика 130/70 °C. Уменьшение расхода теплоносителя в теплосети может быть объяснено уменьшением теплопотерь зданий и более экономического потребления теплоэнергии. Принимая во внимание это обстоятельство, был проведен эксперимент с целью исследовать возможность успешного переноса тепла от ТЦ "Vecmīlgrāvis" понижением температуры теплоносителя в подающем трубопроводе с температурного графика 130/70 °C до 115/70 °C. Надежность и качество теплоснабжения у потребителей должно оставаться неизменным. Расход теплоносителя зависит от тепловой нагрузки потребителей и температуры сетевой воды. Для поддержания выходной температуры из теплоисточника как можно на более низком уровне, необходимо определить верхний предел расхода теплоносителя в теплосети, который зависит от диаметра труб и выбора сетевых насосов.

Технико – экономические показатели ТЦ "Vecmīlgrāvis" были использованы в этой работе для оценки теоретических расчетов.