Damages of the Tallinn District Heating Networks and Indicative Parameters for an Estimation of the Networks General Condition

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***Abstract* – District heating networks in Estonia are mostly old and in bad condition. The state of the district heating networks of Tallinn is typical for the rest of Estonian DH networks. The paper includes an analysis of the Tallinn district heating networks. Valid data about damages in district heating systems received for the last 12 years were used for an analysis of the network damages.**

Different types of network damages are analysed: external corrosion, internal corrosion, defect of installation, factory defects, defect of construction and other reasons. The scale of damages for the different elements of networks is compared in the paper: armature, compensator, construction and pipes. The main factors which influence damages in district heating networks are the age of networks, the quality of construction works and the network operation conditions.

The damage quantity dependence on the age of networks is also defined and analysed in the paper. The scale of damages can be diminished by reducing the average age of the networks. This is possible by replacing old pipelines and other network system elements. The pipes average age changes for a 20 year period are simulated according to different intensities of renovation works.

***Keywords* – District heating, energy efficiency, district heating network.**

I. Introduction

District heating (DH) allows centralized heat production for an area and hot water transportation to the buildings through a network of pipes. District heating systems offer the potential to use renewable heat generation technologies and there are many researches about possibility to use biomass, waste, geothermal energy for district heating systems[1]-[5]. Developed district heating systems promote cogeneration development. Cogeneration using in district heating systems is analysed in many papers[6-9]. District heating system is traditional in Estonia. It provides approximately 70 per cent of all heating in the country. The share of heat produced by combined heat and power production stations is approximately one third. At the same time, the technical condition of the district heating networks (and production equipment) is poor . The unsatisfactory condition of DH networks and unreliable heat supply can place doubt on the future of district heating and consumers can make a choice towards a different heat supply alternative. Often the decentralized heating is not an effective solution for regional heat supply strategy and it decreases the potential of combined heat and power production [10].

Nowadays DH systems operate both in big cities and in small towns, which means, that there is enough heat load for the installation of new cogeneration equipment.

But before new energy sources installation, it is important to define and analyse the situation with DH networks.

The purpose of this paper is to define the valid condition of typical old networks in Estonia, to define the reasons of damage occurrence on the basis of operational data and to make forecasts for the operation of a DH network for the next 20 years. The paper includes analysis of Tallinn district heating networks. The valid data about the damages in district heating systems collected during past 12 years was used for the analysis of networks damages.

II. The Present Condition of Tallinn District Heating System

District heating networks in Estonia are mostly old and in poor condition. The state of the district heating networks of Tallinn is typical for the rest of Estonian DH networks. In Tallinn, the heat is transmitted to the consumers through a 406-kilometre long heating network including 93 km of pre-insulated pipes (23%). The district heating systems of Tallinn were constructed mostly during the 1960-1980 period and their average age is 22 years.

The AS Tallinna Küte enterprise heads the operations of the biggest part of district heating networks and boiler-houses of Tallinn.

District heating systems of Tallinn consist of five districts of the central heat supply: Kesklinna district (total length ~92 km, length on the balance of AS Tallinna Küte ~76 km), Lääne district (total length ~162 km, length on the balance of AS Tallinna Küte ~141 km), Lääne district local networks (total length ~12 km, length on the balance of AS Tallinna Küte ~11 km), Lasnamäe district (total length ~114 km, length on the balance of AS Tallinna Küte ~106 km), Maardu district (total length ~25 km, length on the balance of AS Tallinna Küte ~14 km) [11].

The district heating systems of the areas Kesklinna and Lasnamäe are connected through the pump station Laagna. The total length of heating networks is 406 km from which on the balance of AS Tallinna Küte there are 348 km, or 85,7%.

The following CHP stations and boiler-houses supply heat to the districts of Tallinn: the CHP Iru (natural gas, 190 MWel, 748 MWth), the boiler house Ülemiste (natural gas, 232 MWth); the CHP Väo (wood chips, 25 MWel, 65 MWth); the boiler house Mustamäe (natural gas, 390 MWth); the boiler house Kadaka (natural gas, 290 MWth) .

Besides the abovementioned, there are some small-scale boiler houses. Figure 1 displays the basic scheme of the Tallinn heat supply.

District heating systems of Tallinn were constructed mostly during the 1960-1980 period and their average age is 22 years. The state of DH networks varies for the different districts of Tallinn.

In Lasnamäe, the construction of district heating systems began in 1970, and the network length is ~106 km at the present time. Assuming the actual load, the heating systems of the Lasnamäe district are the most overloaded in town.

The length of the main pipelines DN1000-1200 is ~19 km, the length of pipes DN400-800 is ~4,4 km. The share of the main networks is quite large and it is ~22% of the total network length in Tallinn.

Thermal isolation is made of glass wool according to old soviet building norms and it is the reason for big heat losses in the network. The heat losses in Lasnamäe network in 2008 were 21% from the total produced heat.

The interconnected district heating systems of boiler-houses Mustamäe, Kadaka and Karjamaa (not in operation at present time) are related to the Lääne area (districts Mustamäe and Õismäe). Initially there had been two separate networks which were merged later on as a result of growth. In the area Lääne the construction of district heating systems began in 1960. The length of the Lääne area network is ~141 km. The diameters of the main pipelines are less than those in the Lasnamäe area.

The length of the main pipelines with diameter DN400-900 is ~27,8 km. The heat losses of the network in 2008 were 16% from the total produced heat.

The speciality about the heating system of the area Lääne is that in the past there was an open system of hot water supply. The water added to the system had no time to purify sufficiently and oxygen and water hardness led to an intensive internal corrosion of the pipes.

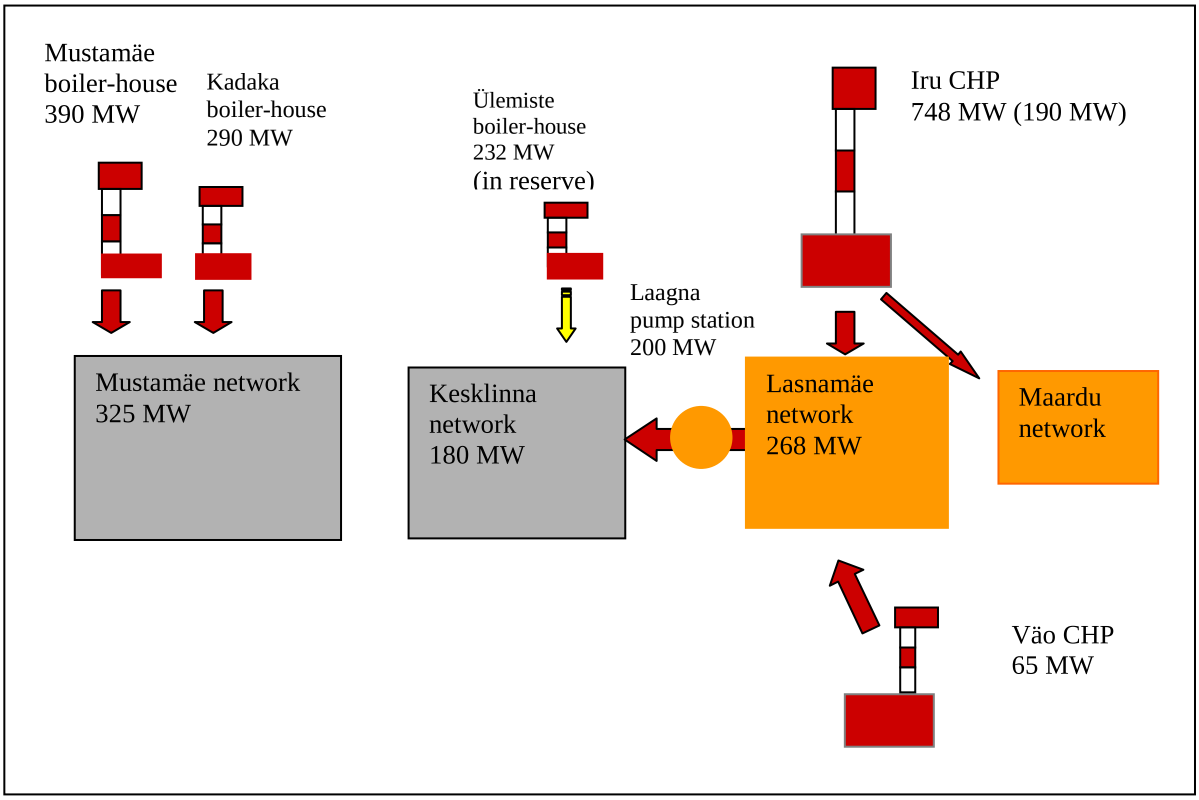

Fig. 1. The basic scheme of the Tallinn district heating system.

In the Kesklinn area, the network construction began in 1959. Initially the heat supply was carried out by the Tallinna Soojuselektrijaam heat and power station and later on by the boiler-house Ülemiste. The district heating system of the Kesklinn area is the oldest in Tallinn. The average age of the Kesklinn area network is 25 years, the total length is ~76 km.

The length of the main pipelines with diameter DN400-900 is ~13,8 km. The share of main pipelines in the Kesklinn area network is ~18,1%. Relative heat losses of the Kesklinn network are within the limits of 15...18%. In comparison with other areas, the relative heat losses are less. The reasons for this are: the bigger network loading, the not oversized pipes and the significant share of pre-insulated pipes [11].

III. The Assessment of Damages

The analysis of the networks' damage statistics for Tallinn is made on the basis of valid data collected during the past 20 years.

The distribution of damages in Tallinn district heating network is shown in Figure 2 according to the periods of construction. It is obvious that the most critical situation is with the sites constructed during the 1980-1985 period. This can be explained by the poor quality of both construction works and materials used in construction. During that period the networks were being constructed in a hurry and with lack of proper supervision.

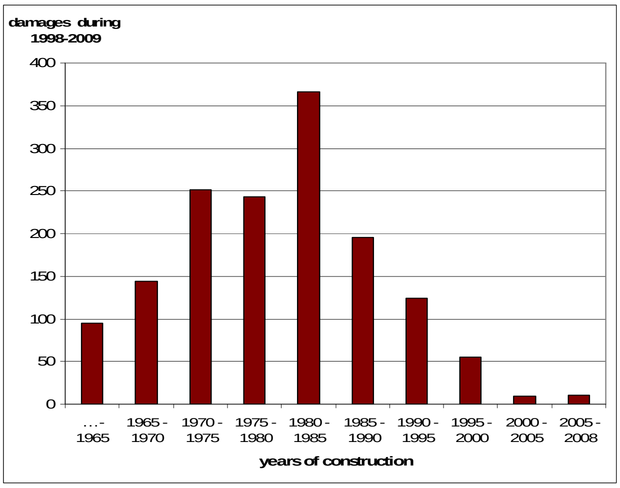

Fig. 2. Damages of the Tallinn district heating networks according the periods of construction.

In Figure 3 the places of damage in the network elements are shown: armature, compensators of thermal lengthening, construction and pipes. The major part of all damages was the pipes.

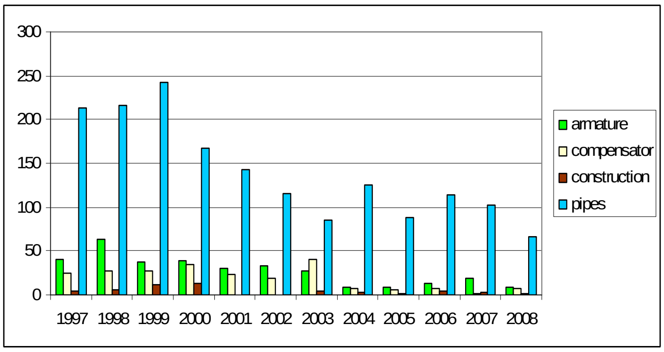

Fig. 3. Places of damage in the Tallinn district heating networks elements.

During the 1997-2003 period there were many problems with armature and compensators; after 2003 the quantity of damages to these elements had considerably decreased. The oldest thermal lengthening compensators work since 1959. The resource of axial compensators is no more than 30 years and by today they are already worn out. The probability of failures sharply increases. Today, the technical condition indicates that 84% of all compensators should be replaced. Some parts of the old locking armature also have to be replaced. The service life of armature has exceeded 25 years. Armature and compensators are partly renovated; however some pieces of it are old and also require replacement [11].

Figure 4 summarizes the nature of damages. There are no data about the character of damage for all the areas of Tallinn within the past 10 years, which is why the damage allocation by character of damage is shown for a five year period.

In the Tallinn network, a significant part of the damages is caused by the external corrosion of pipes. The main reasons for external corrosion are: the poor waterproofing of underground channels and chambers and the collapsed drainage. Amongst other reasons are the defects of pipe supports and the destruction of concrete channels.

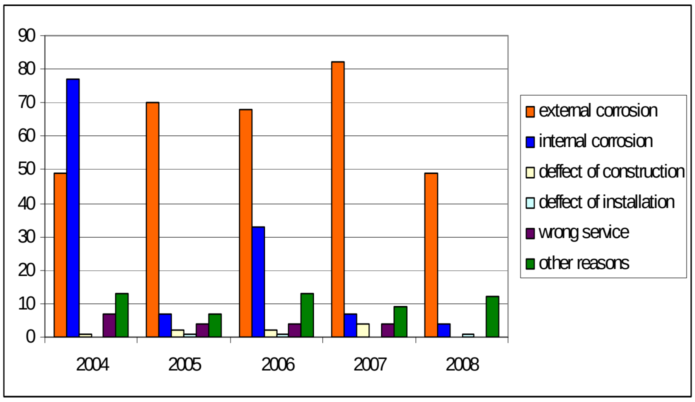

Fig. 4. Nature of damages in the Tallinn district heating networks.

The second main cause of damages is internal corrosion. In 2004 many pipes damaged by internal corrosion were revealed. Internal corrosion is the most serious problem in the Lääne network where an open system of hot water supply has been used in the past. Besides the damages caused by defects of installation, defects of construction, factory defects and improper maintenance, the other reasons have also been registered.

The main factors, which have an effect on the damages in district heating networks, are the age of networks, the quality of construction works and the network operation conditions. The two latter can be regulated by control authorities and proper legislation, however, the influence of these factors has been reduced in comparison with the 1970-1990 period. During this period the quality of construction works was very low, drainage systems were installed incorrectly or were not installed at all and isolation materials were not qualitative. As regards district heating operation conditions, the aforementioned open vented hot water supply system used in some networks has led to intensive internal corrosion of pipes.

One important reason for damages reduction is that, in recent years, the networks have significantly reduced pressure. The network currently works in a stable temperature mode, the reliability of heat sources is improved and the quantity of equipment emergency stops forced by sharp fluctuations of the heat-carrier temperature has decreased.

Another operation condition factor which influenced the number of district heating system damages was higher water temperatures in the networks (up to 130 t°C) than nowadays (up to 110 t°C). Finally we can conclude that such factors as the quality of construction works and the quality of network operation are close to their optimum at present time in comparison with previous years.

The scale of damages also depends on the age of networks. The number of damages can be reduced by reducing the average age of the networks. This is possible by replacing the old pipelines and other networks systems elements.

Reconstruction and replacement works are made in Tallinn, but the intensity of replacement is rather low and not enough for a stable system operation. It is important to define how intensive the network reconstruction should be.

Data for the three past years were used for defining the damage dependence (number of damages/km/year) on the age of the networks. Data about damages were collected for 7 age groups (0-5 years, 5-10 years, 10-15 years, 15-20 years, 20-25 years, 25-30 years, 30-35 years).

Using the least squares analysis, a regression equation for this dependence was defined.

$$D = -0,0096 \cdot A^2 + 1.8985 \cdot A + 1.0496 \quad (1)$$

where
D – Number of damages/100 km per year
A - Age of networks

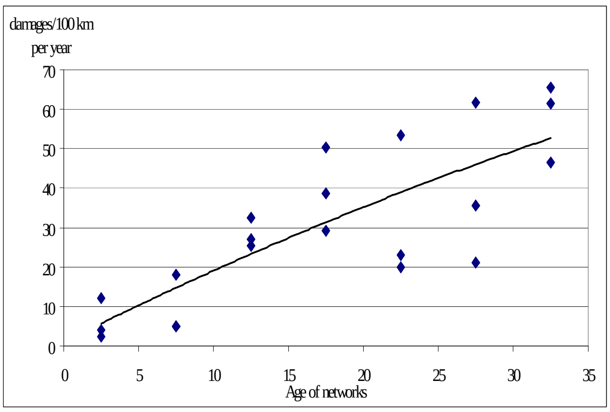

Fig.5. Damage number dependence on the age of pipes in district heating systems for the 2005-2007 period.

Before using this regression for further calculations, we should check if this equation is appropriate. One of the main parameters for estimation of regression equation is the correlation coefficient. It is considered, that the correlation is good in case when R>0.8. In the case of damage dependence on pipes age, R is 0.802. R^2=0.643, which means that the equation characterizes the 64,3% of damage number changes, but the 35,7% of changes are characterized by other factors. There is still an influence of other factors, which can not be changed, such as construction and installation problems in the past.

Data about damages allocation by the group and approximation of these data is shown in Figure 5.

The regression equation can be used for the damage forecasts in the future.

As it has been mentioned before, the age of networks depends on the intensity of renovation works.

In Figure 6, the length of all repaired sites is shown split by years.

Since 1980, the serial repair of the Tallinn district heating system is being carried out.

Basically the investments have been directed towards the increase of reliability and the reduction of quantity and duration of faults in heat supply. It has been invested a lot in the locking armature.

For the past 10 years ~35 km of district heating pipelines have been replaced, which is 10% of total length of the district heating systems in the Tallinn area.

The annual replacement of pipes is in average about 3,06 km per year, which is less than 1 percent from the length of Tallinn DH system pipelines.

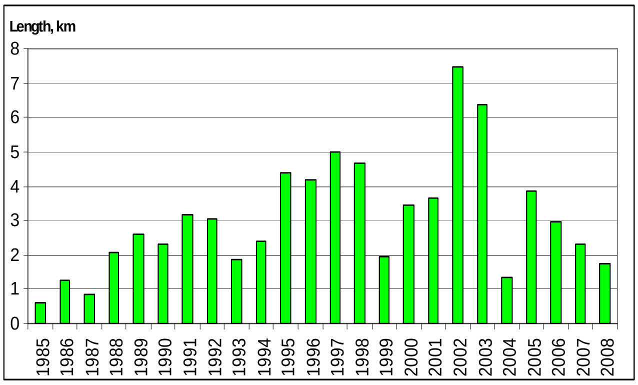

Fig.6. Length of replaced pipelines by years in Tallinn district heating network.

IV. The forecasts for district heating system age

One of the tasks was to assess, how big the renovation works should be in order to stop increasing the average age of pipes. A simulation model, which uses both real data and also some assumptions, was created for such estimation.

Assuming that the length of pipes (360,67 km) will not change during the forecast period and that the annual scope of renovation works will remain the same during the entire period, this means that the length of renovated pipes will also not change. Besides it was assumed that every year just the oldest pipes would be renovated; however in reality the renovation works are based on the pipes actual state estimation.

Allocation of pipes ages for starting point (2008) is shown on Figure 7[11].

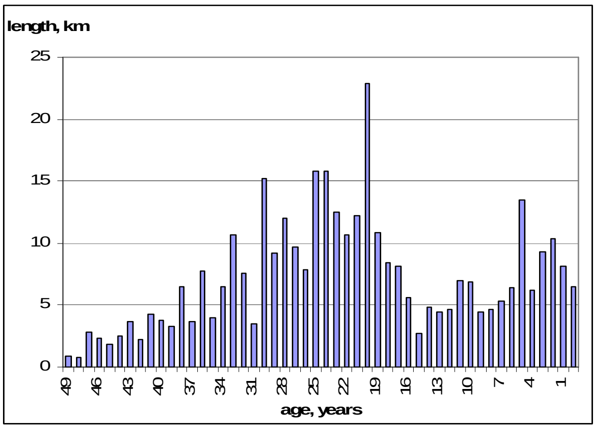

Fig.7. Length of DH networks by pipes age (in 2008).

The average age of pipes for each year was calculated according to equation (2)

$$A_{av} = \frac{\sum_{i=a}^{j} l_i (j-i) - \sum_{i=a}^{b} l_i (j-i) - (j-c)\cdot\left(l_c - \sum_{i=a}^{b} l_i\right)}{l_j} \qquad (2)$$

where

i=b, if $\sum_{i=a}^{b} l_i < l_j$ *; i=c, if* $\sum_{i=a}^{c} l_i > l_j$

A_{av} is average age of pipes in j year

l_i is length of pipes, constructed in i year

i- year of construction;

j- current year;

a- year of construction of the oldest pipes, operating in the current year.

As a result of simulations, seven forecasts for pipes average age were calculated according to different intensity of renovation works: for current intensity of renovation (3,06 km/year) and for intensities when 1%, 1,5%, 2%, 2,5%, 3% and 4% of the total DH system length would be annually renovated. The forecasts were simulated for the 20 year long period.

The results of the simulation are shown in Figure 8.

As it can be seen from Figure 8, in case the renovation stays on the same level, the average age of the pipes will grow till reaching 39 years in 2040. In case the length of annually changed pipes is 1% or 1,5% higher, the average age will still rise, but in a less steep way. When 2% of the DH system length is annually renovated there will be the minimal changes in age during first 5 years, after that the age will start rising and only after 15 years it will begin to decrease.

If renovation intensity is 2,5% of the length or higher, the average age will not rise at all or will decrease. For reducing the damages occurrence probability influenced by the networks age, the amount of repaired sites should be at least 9 km/year. This way the process of ageing will slow down and also the average age will stabilize at a certain mark.

One of the possible solutions is to replace the pipes with higher intensity of 3-4% until reaching the 17-20 years average age and then reduce the length of renovated pipes per year to the 2-2,5% of the whole length of DH network.

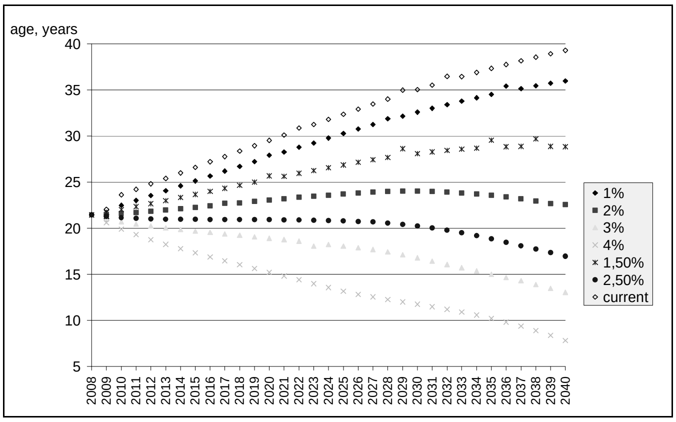

Fig.8. Pipe age forecasts for different intensity of network renovation works.

Increasing of renovation intensity will results not only in reducing of damages amount in district heating systems, but in enlargement of energy efficiency.

During previous research it was calculated, that in case of full reconstruction of district heating system in Tallinn it is possible to reduce heat losses from 18,7% to 6,5% [11]. It will result in saving of fuel used for heat production. As it was described in the second section of paper, natural gas is the main fuel, which is used for heat production in Tallinn. Wood fuel is consumed only for heat produced in CHP Väo, which was taken into account during following calculations.

For calculation of possible natural gas saving due to full reconstruction of district heating system in Tallinn it was assumed, that there will be used existing energy sources, average energy efficiency of energy sources, working on natural gas is 93,7%, heating value of natural gas is 9.35 MWh/1000 m^3.

Due to the saving of natural gas fuel, carbon dioxide emission will reduce. Reduction of carbon dioxide emission was evaluated using standard emission factor for natural gas: 0.202 t CO_2/MWh. As it can be seen from Table 1 reduction of CO_2 emission will be higher than 50 thousands tones per year.

TABLE I

FULL RECONSTRUCTION OF DISTRICT HEATING SYSTEM

Indicator	Current Situation	After Full Reconstruction	Diffe rence
Heat Production (MWh/year)	2087855	1854331	
Heat Consumption (MWh/year)	1698347	1734168	
Heat looses (%)	18,7	6,5	12.2
Natural gas consumption for heat production (1000 m^3/year)	238313	211658	26655
CO_2 emissions (t/year)	450103	399760	50343

Therefore district heating renovation measures are having not only positive technical aspects, but very important favourable environmental aspects.

V. Conclusion

District heating networks in Estonia are mostly old and in poor condition. The state of the district heating networks of Tallinn is typical for the rest of Estonian DH networks. Thus the results of damage analysis made for the DH network of Tallinn can be used for the other networks in Estonia.

The AS Tallinna Küte enterprise manages the operation of 85% from the length of district heating networks in Tallinn. Tallinna Küte data about the damages were used for assessment.

Places of damages in the DH system are the ollowing: armature, compensator, pipes and construction. Most of the damages happened in the pipes.

As regards the character of damages, the typical damages are caused by external corrosion, internal corrosion, defect of construction, defect of installation and improper maintenance. The majority of damages are caused by the external corrosion of pipes.

The age of networks, the quality of construction works and the network operation conditions are the most important factors, which influence the damages in district heating networks. The number of damages can be reduced by reducing the average age of the networks. This is possible by replacing the old pipelines and other networks systems elements. The intensity of replacement works during last 25 years was less than one percent from the whole length of pipes.

Seven forecasts for pipes average age according to different intensity of renovation works were simulated: for current intensity of renovation (3,06 km/year) and for intensities when 1%, 1,5%, 2%, 2,5%, 3% and 4% of the total DH system length would be annually renovated. It was concluded, that for maintaining the networks average age at least at former level, the rate of old pipelines replacement should exceed 2,5% of the whole length of DH system.

District heating renovation measures are having not only positive technical aspects, but very important favourable environmental aspects. According to calculaitons in case of full reconstruction of district heating system in Tallinn reduction of CO_2 emission will be higher than 50 thousands tones per year.

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Aleksandrs Hļebnikovs, Anna Volkova, Olga Džuba, Arvi Poobus, Ülo Kask. Tallinas siltumtīklu bojājumi un tīklu stāvokļa novērtējuma indikatīvie parametri
Igaunijā pārsvarā ir veci siltumtīkli, turklāt sliktā stāvoklī. Tallinas centrālās apkures tīklu stāvoklis ir tipiskais Igaunijas siltumtīklu lielākajai daļai. Rakstā veikta Tallinas centrālās apkures tīklu analīze. Ticami dati tika saņemti par 12 gadiem un izmantoti tīklu bojājumu analīzei.
Dažādiem siltumtīklu bojājumiem tika izanalizēti: ārējā korozija, iekšējā korozija, uzstādīšanas defekti, rūpnīcas defekti, būvniecības defekti un citi. Rakstā tika salīdzināti dažādu tīkla elementu bojājumi: armatūras, kompensatoru, cauruļu un konstrukciju.
Galvenie faktori, kuri ietekmē bojājumu daudzumu, ir tīklu vecums, būvniecības darbu kvalitāte un tīklu darbības apstākļi.
Šajā rakstā ir noteikta un izanalizēta bojājumu daudzuma atkarība no tīklu vecuma. Bojājumu daudzumu var samazināt, nomainot vecos cauruļvadus un citus tīkla elementus. Siltumtīklu cauruļu vidējais vecums tuvākajiem divdesmit gadiem tika prognozēts, ņemot vērā renovācijas darbu dažādo intensitāti.

Александр Хлебников, Анна Волкова, Ольга Джуба, Арви Пообус, Уло Каск. Повреждения Таллинских тепловых сетей и индикативные параметры для оценка состояния сетей
Тепловые сети в Эстонии главным образом старые и в плохом состоянии. Состояние сетей центрального отопления Таллинна типично для большинства эстонских теплосетей. Статья включает анализ сетей центрального отопления Таллинна. Достоверные данные были получены за последние 12 лет и использованы для анализа повреждений сетей.
Различные типа повреждений сетей были проанализированы: внешняя коррозия, внутренняя коррозия, дефекты установки, фабричные дефекты, дефекты строительства и другие дефекты. Повреждения в различных элементах сетей были сравнены в статье: арматура, компенсаторы, трубы и конструкции.
Главные факторы, которые влияют на количество повреждений это возраст сетей, качество строительных работ и условия работы сетей.
Зависимость количества повреждений от возраста сетей определена и проанализирована в статье. Объем повреждений может быть уменьшен за счет уменьшения среднего возраста сетей. Это возможно при замещении старых труб и других элементов сетей. Средний возраст труб на ближайшие двадцать лет был спрогнозирован с учетом различной интенсивности работ по реновации сетей.