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ESTIMATION OF EXISTING DISTRICT HEATING DISTRIBUTION NETWORK FROM THE STANDPOINT OF LIFE CYCLE ANALYSIS

Artur Rogoža

Dept of Heating and Ventilation, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-2040 Vilnius, Lithuania. E-mail: artur.rogoza@ap.vtu.lt

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Abstract. Life cycle analysis is a widespread method in most countries. Its principle is to evaluate direct and indirect influences of searching object on environment during its all life cycle. Life cycle model calculations of two existing district heating distribution networks were investigated in this case. Two variants of district heating network maintenance works were computed and compared: renovations using pipes assembled in channels and pre-insulated pipes technologies. Primary energy, heat losses, expenses for maintenance works and heat losses were calculated. The most suitable periodicities of maintenance works and character of the networks depreciation using those periodicities were determined.

Keywords: district heating distribution network, life cycle analysis, system analysis, life span, depreciation, energy saving, planning of maintenance works.

1. Introduction

Life cycle analysis (LCA) is a quite old and widely used method. Its roots have been developed since 1970. All LCA research works were directed at energy efficiency of natural resources. LCA was supplemented with ecological aspects later – it was started to estimate an influence on environment, because every product becomes a waste; besides, harmful materials are extracted during its production. A lot of works were prepared for packaging materials in this field because these materials form the main part of household wastes. However, LCA method became also popular investigating large objects, as buildings [1, 2], technical systems [3], etc. One of them is the district-heating system that has been investigated only in environmental aspects till now [4].

District heating network (DHN) is a technical system that must be operated using comprehensively effective algorithm. The general goal of this work is to present the principles, possibilities and results of this algorithm for district heating distribution network using LCA method.

The specific goal is to evaluate the existing district heating distribution network in terms of LCA (energy and economical evaluation) during the calculating time if there are two ways of network renovation works (pre-insulated pipes and pipes in channels) and to determine periodicity of those works at a minimal demand of energy and expenses.

2. Methodology

LCA is the estimation of direct and indirect influence of a product on environment during its all life cycle ("from-cradle-to-grave"). It gives an opportunity to determine the product factors influencing the environment and society using energy or multiple criteria evaluation [5]. The complex evaluation of those factors serves for making sustainable decisions, economical, energy and environmental solutions. "Life-cycle analysis is a method for calculating all the social and environmental impacts of a given technological solution, from procurement of resources and materials to waste treatment and final disposal or recycling" [3].

However, LCA method is aimed at materials (elements) of a product (object), so another tool is needed to split the object. System analysis is the tool to be used to do it. There can be established the elements, their functions, interactions and weight factors using the system analysis. In this case, weight factors of separate elements were determined according to the primary energy used to create those elements.

2.1. Models

The life cycle computer model (LCM) was created for district heating network according to the aforesaid methods. All basic calculations were done applying this model. The main data for LCM are: length, diameter and age of pipelines. The data were collected from district heating companies [6]. As additional data an information about primary energy use for elements creation [7] and costs of network maintenance works was used [8].

The main aim of this model is: to calculate energy and expenses for DHN maintenance works during a fixed period, and to determine the optimal periodicity of the maintenance works.

Depreciation model of the elements was introduced into LCM. It was prepared according to the technological model of building life cycle [9]. The depreciable value of the elements and whole network can be evaluated by it.

3. Description of the objects

Two district-heating networks were investigated – DHN in Lentvaris and Zarasai.

There are two separate networks in Lentvaris: south and north. The south-side network was examined in this work. Heat capacity of south-side boiler house is 16 MW. The main fuel used in this boiler house is natural gas. Total length of south-side network is 8275 m. Only 1 % of those pipelines are pre-insulated pipes. Other pipelines of south-side network consist of two-pipes assembled in concrete channels. Diameters of the pipes vary from 32 to 300 mm, time of the major repairs – from 1985 to 2001. Detailed data of south-side DH pipelines in Lentvaris are presented in Table 1.

Table 1. Data of district he ating pipelines in Lentvaris

Diameter (mm)	Length		Average age (years)	Major repairs	
	(m)	(%)		(m)	(%)
Two-pipes assembled in channels					
32	566,5	6,8%	15	0	0,0%
40	27	0,3%	15	0	0,0%
50	1165	14,1%	14	98,5	8,5%
70	784,2	9,5%	15	0	0,0%
80	1252	15,1%	14	71	5,7%
100	1083,8	13,1%	14	163,3	15,1%
125	239,6	2,9%	14	0	0,0%
150	1922,7	23,2%	15	269,6	14,0%
200	455,1	5,5%	14	0	0,0%
300	696,5	8,4%	16	82,5	11,8%
Sum	**8192,4**	**99,0%**	**14**	**684,9**	**8,4%**
Pre-insulated pipes					
250	**82,5**	**1,0%**	**1**	**0**	**0,0%**
Total	**8274,9**	**100,0%**	**14**	**684,9**	**8,3%**

The second research object is DH distribution system in Zarasai. Three DH networks with three boiler-houses (RK-1, RK-3, RK-4) are installed in Zarasai. Two of them (RK-1, RK-3) are investigated in this case. Heat capacity of each of them is 10 MW. The main fuel is residual fuel oil (in RK-1) and light oil (in RK-3). Both networks consist of four-pipes assembled in channel pipelines. Diameters of the pipes vary from 25 to 200 mm, time of the major repairs – from 1968 to 1993. No major repairs of pipelines have been performed.

The number of leaks per 1 km depending on the age of pipelines is presented in Fig 1. It can be seen that the number of leaks for pipes older than 25 years considerably increases.

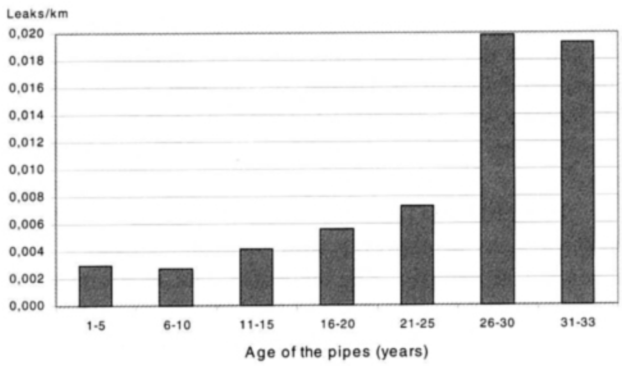

Fig 1. The number of leaks per 1km of pipes depending on their age

The total length of two networks in Zarasai is 5886 m. The average age of the pipes is 21 years. A more detailed information about the network is presented in Table 2.

Table 2. Data of district heating pipelines in Zarasai

Diameter (mm)	Length		Average age (years)
	(m)	(%)	
25	28	0,5%	15
32	113	1,9%	15
40	95	1,6%	17
50	790	13,4%	18
70	427	7,3%	19
80	1277	21,7%	20
100	2083	35,4%	20
125	256	4,3%	28
150	737	12,5%	26
200	80	1,4%	34
Sum	**5886**	**100%**	**21**

4. Results

Two variants of the calculations were done. It was assumed that the network maintenance works would be performed using the existing type of pipelines (assembled in channels) in the first variant and using pre-insulated pipes – in the second one.

In the first variant, pipelines were divided into three components: pipes, insulation and channels. It was assumed that combination of maintenance works could be of three kinds:

1. Changing of insulation only;
2. Changing of depreciated pipes and insulation;
3. Changing of channels, pipes and insulation (full changing).

The most effective periodicity of the maintenance works in terms of life cycle was calculated. There were used the preliminary intervals of life spans for the elements of the networks in the calculations: 10-20 years for insulation, 25-45 years for pipes and 50-70 years for concrete channels.

The second variant of the calculations is related to evaluation of DH networks using pre-insulated pipes to change depreciated pipelines. The methodology of those calculations is similar to the first variant. The difference is that pre-insulated pipes cannot be changed by elements – it is an integral element. Most manufacturers of pre-insulated pipes guarantee 50 years life span for their products [10]. However, examining statistical data of leaks in networks with pre-insulated pipes, the situation is different. The statistical data of Finnish district heating distribution networks [11] were investigated, as practice of Lithuanian district heating companies is not long using pre-insulated pipes. It was determined that the most part of leaks occurs in the span of 16-30 years. Therefore, the calculations were done for variants if life spans for pre-insulated pipes are 30-50 years.

All calculations were performed for a fixed period of 50 years.

4.1. Estimation of district heating network in Lentvaris

Depreciable value of district heating network in Lentvaris was calculated using depreciation model. It was determined that this depreciable value is equal to 57 %. Evaluating DHN in Lentvaris in terms of life cycle, its primary energy consumption for the network creation was 8963 MWh.

In the first variant (look Chapter 4) of calculations, the best combinations of the maintenance works with minimal primary energy consumptions and heat losses in the network during a fixed period of 50 years were determined.

Fig 2 shows that the minimal energy consumptions correspond to combinations 10-37-(66÷70). Thus the insulation has to be changed every 10 years, insulation and pipes – every 37 years and whole pipelines complex – every 66÷70 years. Also, there were determined the best combinations of the maintenance works with minimal expenses for heat losses and maintenance works. The graphic results of those calculations are presented in Fig 3.

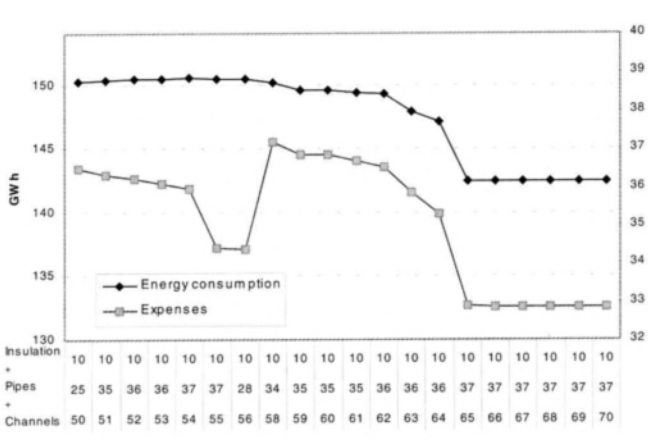

Fig 2. Energy and expenses for maintenance works and heat loss if energy consumption is minimal

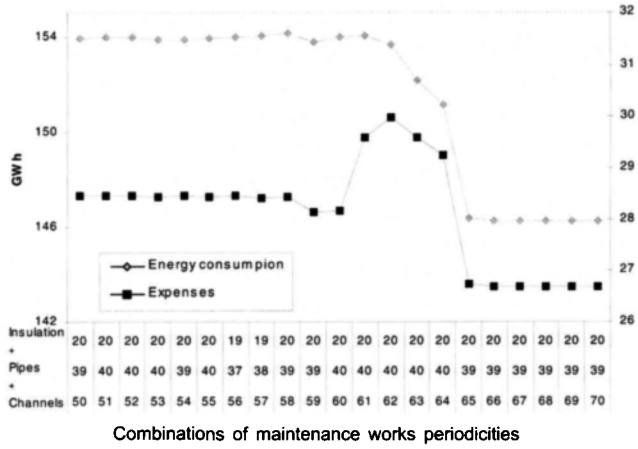

Fig 3. Energy and expenses for maintenance works and heat losses if expenses are minimal

In this case, the minimal expenses for maintenance works and heat losses correspond to combinations 20-39-(66÷70). Because the combinations of maintenance works of two calculations (by minimal energy consumption and minimal expenses) are different, it has to be found the way to evaluate the best combination in two standpoints. Therefore, an energy-economical factor was created. This factor can be determined expressing minimal and maximal values of energy and expenses of all calculated maintenance works combinations by 0 and 1. In this way, the value of the factor of any combination must be between zero and one. Factors of energy consumption and expenses can be calculated using equations (1) and (2):

$$e = 1 - \frac{E_{max} - E}{E_{max} - E_{min}}, \quad (1)$$

$$p = 1 - \frac{P_{max} - P}{P_{max} - P_{min}}, \quad (2)$$

$e(p)$ – energy consumption (expenses) factor (between 0 and 1); E_{max} (P_{max}) – maximal value of combinations energy consumption (expenses); E_{min} (P_{min}) – minimal value of combinations energy consumption (expenses); $E(P)$ – energy consumption (expenses) of searching combination.

To evaluate e and p factors as single factor, a weight coefficient for each of factors has to be attached. Then energy-economical factor can be expressed by equation (3):

$$k = e \cdot s_e + p \cdot s_p, \quad (3)$$

k – energy-economical factor of combination; s_e (s_p) – energy (economical) weight coefficient ($s_e + s_p = 1$).

It was assumed in this work that the weight coeffi-

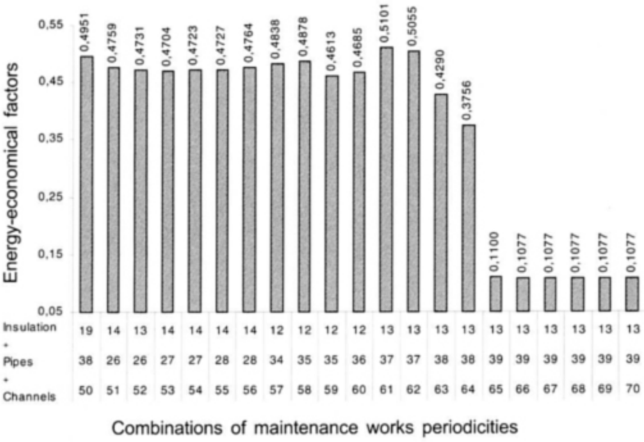

Fig 4. Energy-economical factors for different maintenance work combinations in Lentavaris DHN

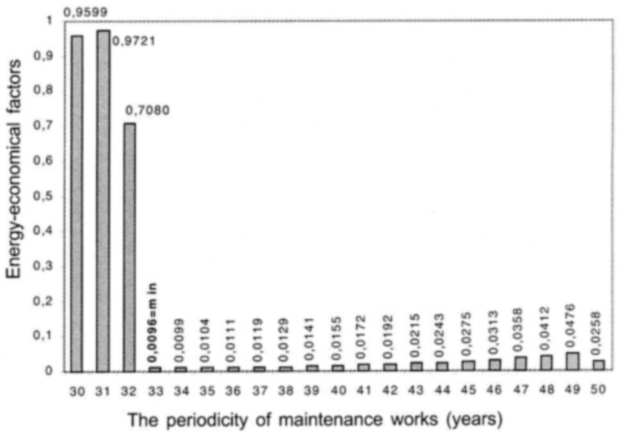

Fig 6. Energy-economical factors corresponding to maintenance works periodicity for pre-insulated pipes of DHN in Lentvaris

cients are equal ($s_e = s_p = 0{,}5$). Energy-economical estimation was done using equations (1–3). The results of the estimation are presented in Fig 4. We can see that the minimal value of the factor k corresponds to life span of the channels in the interval of 66–70 years, pipes – 39 years and insulation – 13 years.

Using the calculated combination of the maintenance works during a fixed period of 50 years, primary energy consumption would be 4,63 GWh, heat losses – 139,53 GWh, expenses for maintenance – 12,6 mill Lt and expenses for heat losses – 15,2 mill Lt.

Depreciation timetable (Fig 5) of district heating network in Lentvaris and its elements were created for the calculated combination of maintenance works.

As we can see in the Fig 5, the depreciable value of the network would be equal to about 25 % after 50 years. It means that the most part of the network elements has to be changed immediately. Therefore, it would be reasonably to put new technologies into practice at that time, ie "standard", "ztwins" pre-insulated pipes or not existing (at present) types of pipelines.

In the second variant (look Chapter 4) of calculations, the best periodicity of the maintenance works (changing existing pipelines by pre-insulated pipes) during a fixed period of 50 years was determined. An analogical algorithm of the calculations to pipelines assembling in the channels was done. The results of energy-economical factor calculations for pre-insulated pipes are presented in Fig 6.

As we can see in the figure, the minimal value of energy-economical factor corresponds to pre-insulated pipes changing periodicity of 33 years. Using this periodicity for maintenance works, primary energy needs during 50 years would be 5,89 GWh, heat losses – 107,50 GWh, expenses for maintenance works – 7,8 mill Lt and expenses for heat losses – 11,7 mill Lt.

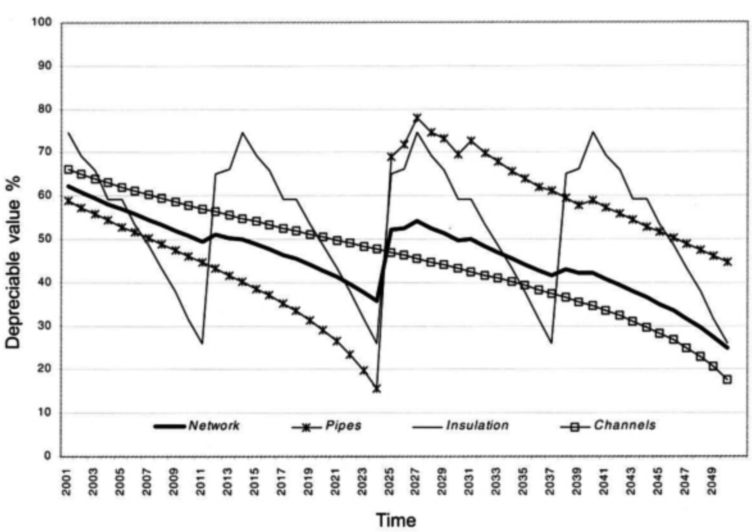

Fig 5. Timetable of DHN in Lentvaris depreciation

4.2. Estimation of district heating network in Zarasai

Evaluating DHN in Zarasai in terms of life cycle, primary energy consumption for network creation was 4922 MWh. Depreciable value of this network was calculated using a depreciation model and it was equal to 56 %.

Solving the first variant (look Chapter 4), analogical calculations to DHN in Lentvaris were performed. Because the combinations of maintenance works of two calculations (by minimal energy consumption and minimal expenses) were different, energy-economical factor was calculated (Fig 7).

We can see that the most suitable combination of the maintenance works periodicity is 17-34-68 in this case.

Using the calculated combination of the maintenance works during a fixed period of 50 years, primary energy consumption would

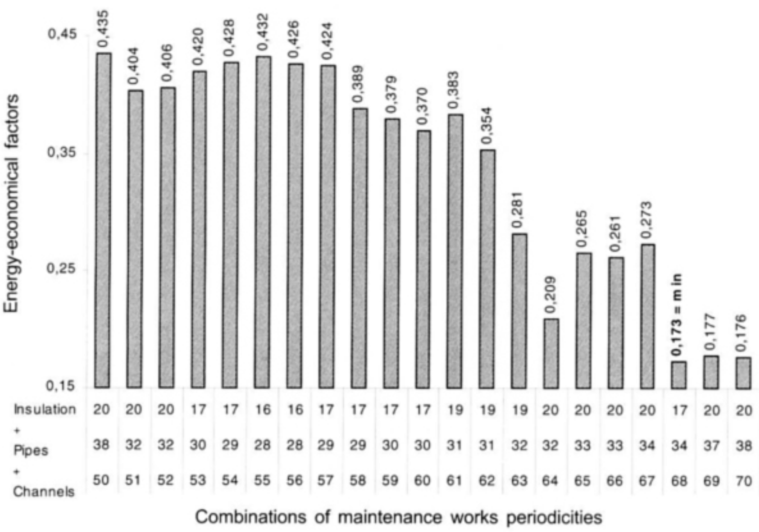

Fig 7. Energy-economical factors for different maintenance works combinations in Zarasai DHN

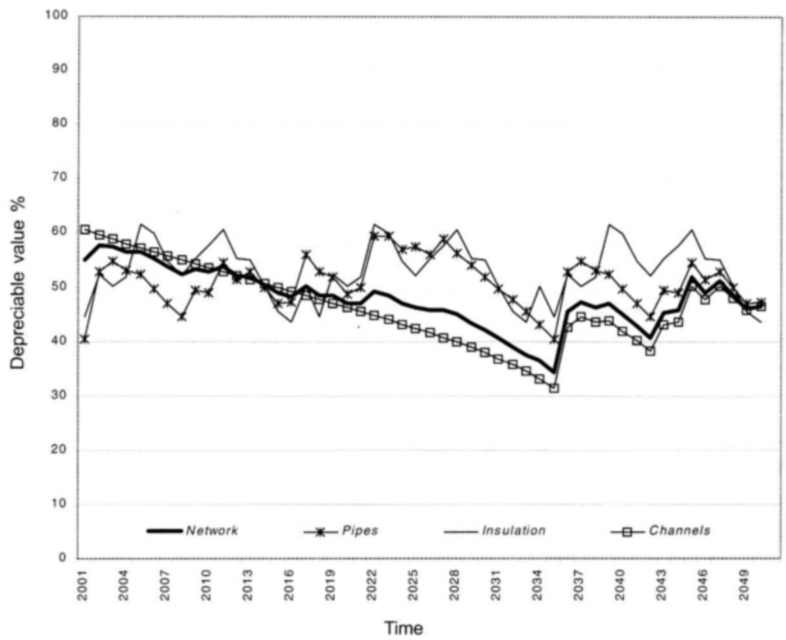

Fig 8. Timetable of DHN in Zarasai depreciation

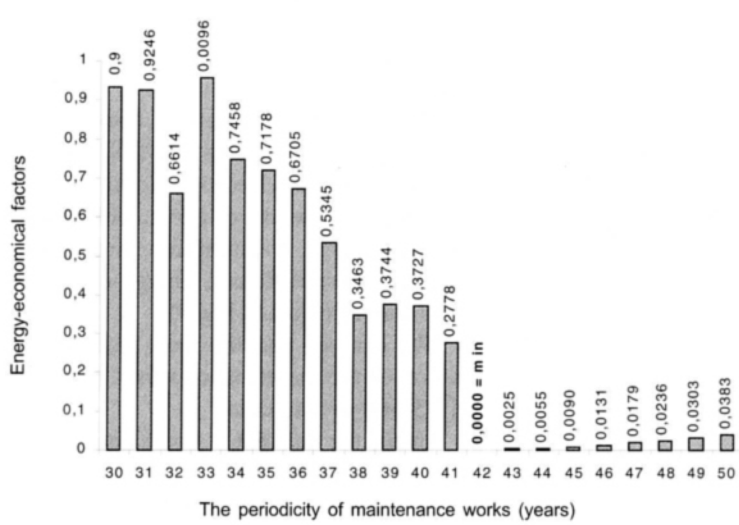

Fig 9. Energy-economical factors corresponding to maintenance works periodicity for pre-insulated pipes of DHN in Zarasai

be 4,36 GWh, heat losses – 100,55 GWh, expenses for maintenance works – 5,9 mill Lt and expenses for heat losses – 11,0 mill Lt.

Also, depreciation timetable (Fig 8) of district heating network in Zarasai and its elements were prepared for the calculated combination of maintenance works.

In this case, the most suitable time to change the most existing pipelines and to improve them by new technologies should be about 2035 year using calculated combination of maintenance works.

In the second variant (look Chapter 4) of calculations, the best periodicity of the maintenance works changing existing pipelines of DHN in Zarasai by pre-insulated pipes during a fixed period of 50 years was determined. The results of energy-economical factor calculations for pre-insulated pipes are presented in Fig 9.

The minimal energy-economical factor (Fig 9) corresponds to maintenance works periodicity of 42 years. It is equal to zero, and this periodicity corresponds to the minimal value of energy consumption and the minimal expenses.

5. Conclusions

1. A new research area was investigated using life-cycle analysis method – maintenance works of district heating network were examined in terms of energy and economy standpoints.

2. Searching the most suitable periodicity of DHN maintenance works, it was determined that the results are different calculating by minimal energy and minimal expenses means.

3. Energy-economical factor was created and used to define the most suitable periodicity of maintenance works from two standpoints – minimal energy consumption and minimal expenses.

4. The calculated periodicities of maintenance works were different for each district-heating network, so the periodicity of maintenance works should be determined for each network separately.

5. According to the calculations of two variants of DH network renovations in energy and economical points of view it was determined that pre-insulated pipes technology is better than the technology of pipes assembled in channels.

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