RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Power Engineering

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Power and Electrical Engineering Doctoral Program

OPTIMIZATION OF A BIOFUEL DISTRICT HEATING SYSTEM OPERATION

Summary of thesis of Scientific Degree of the Doctor
Engineering Sciences

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PROMOTIONAL STUDY IS PROPOSED FOR ACHIEVING DR.SC.ING DEGREE AT RIGA TECHNICAL UNIVERSITY

Promotional study is proposed for achieving Dr. Sc. Ing degree and will be publicly presented on _____________ 2005, at Faculty of Power and Electrical Engineering, 1 Kronvalda boulevard, in the assembly hall.

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CONFIRMATION STATEMENT

Hereby I confirm that I have developed the present promotional study, which is submitted for consideration at Riga Technical University for achieving Dr. Sc. Ing. degree. This promotional study is not submitted to any other university for achieving a scientific degree.

Valdis Vitolins ______________________

Date

Promotional study is written in Latvian language and contains introduction, 4 chapters, conclusion, bibliography, 53 figures, 105 pages in total. Bibliography contains 97 titles.

Table of contents

Generic description of the thesis

Importance of the theme

District heating is used in 60 % of the households in Latvia. This great ratio indicates the necessity for local authorities to place high emphasis to effective energy generation, management and utilization of heat. Different energy efficiency increasing activities are performed in order to achieve this aim. Heating systems undergo active reconstruction and reorganization. Local authorities often participate in projects of boiler-rooms' reconstruction. Such participation does not only implement reduction of rate increase process, but also helps in socio-economic issue of effective combustion of wood residues in boiler furnaces. The problem of greenhouse gas emissions reduction also becomes more and more relevant.

Latvia joined the United Nations Framework Convention on Climate Change. This membership obliges our country to reduce volume of GHG emissions into the atmosphere. According to the convention Latvia and other member countries in the period of years 2008 till 2010 are to achieve the GHG emission level of the year 1990. Taking into consideration the present pace of development, Latvia is able to accomplish this task. Still, rapid CO2 emission increase can be expected if the process of economical development will accelerate while the energy efficiency level of the national economy will remain at present low level. It is evident that the only means to reduce GHG emissions volume in the field of power engineering is use of high energy efficiency technologies and use of biomass for GHG mitigation. In order for Latvia to make headway in increasing the ratio of efficient biomass use projects, it is necessary to investigate all the factors influencing the projects.

There were two types of information sources researched in the process of the development of the thesis.

1. Analysis of operating data for ready-built boiler hoses, which operate using woodchip (or woodchip and sawdust mixture) fuel with high-energy efficiency (greater than 80%).
2. Research and analysis of informative materials has been made. In order to reduce investment risk gathered information included factors of successful or unsuccessful implementation of wood-chip boiler house projects and potential projects of District Heating systems reconstruction in the near future.

The aim of the thesis

The aim of the research described in the thesis is to develop methods for evaluation of technical, economical and environmental aspects of possibility to use biofuel as an energy resource for district heating, and also to provide the necessary computer software support. The following research tasks were stated:

To choose criteria for selection of a district heating fuel project.
To develop a two-stage evaluation system method for evaluation of energy source for local authorities from technical, economical and environmental aspects.
To develop an empirical model in the form of regression equation for energy source consumption volume (both biofuel and power). The model is based on the measurement data collected in the period of several years for the operation parameters of a biofuel (wood chips) boiler house. It is developed using methods of mathematical statistics.
To develop and to substantiate a method for determination of optimal parameters for the district heating system operation.

Method of research

There are two methods accomplished in the thesis.
1. Researches based on decision theory and on practice. Analysis of existent processes of heat supply enterprises has been made based on the research. The analysis guarantees sustainability of investments for implementation of use of wood fuel in different facilities, e.g. in rural municipalities, in towns and regions. It is based on the results of the projects of effective wood projects that were implemented in Latvia and on evaluation of the potentially implemented projects.

2. Method of optimization of district heating systems operation. Method of optimization is offered for determination of energy efficiency measures. Operation parameters of a woodchip boiler house were analyzed using the methods of mathematical statistics - correlation and regression analysis. The analysis was based on the data collected in 7 years period. Verification of conditions for correct use of regression analysis was performed. The results of mathematical model's calculation were verified with the use of empirical data of district heating operation.

Scientific significance

There is a group of criteria introduced in the thesis for identification of success or failure parameters for district heating system reconstruction projects in municipal district heating companies in Latvia. An optimization model is developed and approbated. With the help of this model is possible to make an analysis of a district heating in order to define the optimal set of energy efficient activities for those boiler rooms in Latvia in which high energy efficiency level of wood fuel combustion is achieved.

Optimization method of energy efficiency increasing activities with selected optimization criteria and appropriate criterion function is introduced in the thesis. This method is used for selection of the most profitable activities. A set of independent parameters has been defined and its significance in energy balances of systems has been analyzed while performing the analysis of existent processes of heat supply enterprises. The set of parameters determines wood fuel and power consumption volume. An empirical equation (model) that describes energy resource consumption for a district heating was introduced. Indicators describing woodchip, sawdust and power consumption for district heating were selected as a result of comparison.

Practical significance

The number of potential users of the methods that are developed in the doctoral thesis is very large. Application of results obtained with the help of model depends on future use:

District heating companies - technical, economical and ecological parameters of a boiler room can be estimated with the help of criteria introduced in the methods and with the help of optimization methods.

Municipalities - selection of the fuel in order to ensure stability of operation of the district heating system with higher efficiency and lower rates of energy generation can be estimated with the help of criteria introduced in the methods.

Investors - methods provide possibility for investors to research possibility of investments in heating company

State - readiness and interest of local authorities to perform reconstruction of district heating can be analyzed with the help of criteria introduced in the methods. District heating condition and usefulness of the reconstruction can also be estimated.

Approbation

The results of the thesis were reported and were discussed:

1. Blumberga D., Vitolins V. Analysis of energy efficiency changes in district heating and their influence on the rates, 42nd RTU Scientific conference Riga, Latvia, October llth - 13th 2001.
2. Blumberga D., Vitolins V. Analysis of energy efficiency changes in district heating and their influence on the rates. 43rd RTU Scientific conference Riga, Latvia, October l0th - 14th, 2002.
3. Latvian experience in heat supply system reconstruction, Seminar for the employees of local authorities and house managements in Liepaja, Liepaja, Latvia. April 10th. 2002.
4. Effective heat furnace and its components. Seminar for the employees of local authorities and district heating, Riga. Latvia, March 15th, 2003.
5. Regulations for heat supply system elements maintenance and automation of engineer systems in a building, Seminar for the employees of local authorities and district heating, Riga, Latvia, April 20th, 2003.
6. Implementation of environmental project in the sector of power industry. Methods of research. 44th RTU Scientific conference Riga. Latvia. October! 1th - 13th, 2002.
7. International conference"Applied Research of Heat Consumption of Dwelling Buildings." Warsaw. Poland, March 21^{SI} - 23rd, 2004.
8. Analysis of increasing of energy efficiency. Building as an element of district heating. 45th RTU Scientific conference Riga, Latvia, October 15th-16th, 2004.
9. International conference" ESCO implementation in energy sector", Berlin, Germany, March 22nd - 24th. 2004.

10. International conference" ECEEE summer study", Mandelieu La Napoule, France, May 30th - June 4th, 2005

The model is used for determination of energy efficiency activities for operation of district heating system in Broceni.

Publications

1. Rudzitis A., Vitolins V. Reconstruction of district heating system in Broceni - *Enerģētika un pasaule.* 2002, Nr.l, pages 66-67.

2. Blumberga D., Vitolins V., Orlovs R., Bedritis E. Model of power using equipment in local authorities. Rate analysis. RTU scientific articles. Power and electrical engineering. Riga, 2002. Part 4. volume 6, pages 130-145.

3. Blumberga D., Vitolins V. Benchmarking of initial Data for Energy performance in Buildings in Latvia/ EC JRC conference papers Dynamic Analysis and Modeling Techniques (DAME-BC), November 13-14,2003, Ispra, Italy

4. Blumberga D., Vitolins V., Orlovs R. Implementation of environmental project in the sector of power industry. Methods of research. RTU scientific articles. Power and electrical engineering. Riga, 2003. Part. 4, volume 9, pages l72-178.

5. Blumberga D., Vitolins V.. Rochas C. Analysis of increasing of energy efficiency. Building as an element of district heating. RTU scientific articles. Power and electrical engineering. Riga, 2004. Part 4, volume 12, pages 152-161.

6. Blumberga D., Vitolins V. Experience on screening participants of energy efficiency projects. ECEEE summer study, May 30-June 4, 2005, Mandelieu La Napoule, France.

7. V.Vitolins, D.Blumberga (2005) Correlation Analysis of Parameters of Brocenu District Heating System, RTU scientific articles. Power and electrical engineering, (accepted for publication) 9 pages.

8. Blumberga D.. Vitolins V. Evaluation methodology and experience for sustainable energy efficiency projects.

9. V.Vītolins. D.Blumberga Regression analysis of empirical data of District Heating systems on biofuel. Latvian journal of physical and technical sciences. 2005, No4.

Framework and volume

The thesis consists of introduction. 4 chapters and conclusion. It contains 105 pages, including 53 figures un bibliography with 97 literature sources. Literature review is not included into the summary.

1. Valuation of biofuel sources in Latvia

Energy efficiency and biofuel implementation projects become more and more popular both in Latvia and Eastern Europe since the acceptance of The Kyoto Protocol. Many of them are realized in the frameworks of international cooperation programs.

Since the beginning of the 1990's different programs connected to the two most essential problems of the use of energy sources were implemented in the power sector of Latvia:

- increase of renewable energy use;
- efficient use of energy - increase of energy efficiency on all levels of the energy system (generation, transportation and consumption).

Many projects were implemented with different results. There were more and less successful solutions. Unfortunately, there were also projects that had to be rated as negative examples. Evaluation method based on the achieved experience and in the analysis is developed in order to determine a successful project on its initial stage and to avoid failures in the future. Method of the project evaluation based on the analysis of a particular example is reviewed in the thesis. That is why the necessary information can be obtained by analyzing process of such projects realization in Latvia.

1.1. Method of valuation

An optimal method of data obtaining, which will allow collecting reliable data, has to be chosen for the information obtaining process. Methods of data obtaining differ and each of them has its own advantages and disadvantages. Because of this it is often necessary to combine them together. The following methods are often used: direct measurement, observations and verifications, questionnaires, archives records.
The aim of the obtained information proceeding and the method, consequently, are devoted to the search of the answer to the questions stated in the research. I.e., to define the criteria of success for energy efficiency projects and to test them in order to find the energy sources and companies that are potentially capable and ready to participate in the realization of such a project. The method **is** developed based on the selection of the most significant criteria and their inclusion into the questionnaire forms.

1.2. Valuation criteria

Significance of the defined criteria is never the same in the decision making. There are criteria that influence the decision substantially, and very insignificant criteria. As wide as possible criteria range has been studied. This implies that the relative meaning of criteria has to be evaluated numerically. Five-grade system can be used for numerical valuation of criteria. A significant criterion is rated with 5 points and insignificant criterion - with 1 point. Valuation of the selected criteria significance is shown in Table 1.1.

Table **1.1.**

Valuation of criteria

Nr.	Criterion	Valuation of significance
1	Size of investments	5
2	Evaluation of the performed reconstruction project	5
3	Readiness of district heating company and it's management participate in energy efficiency projects	4
4	Energy consumer's characteristic on the current territory or company	2
5	Energy tariff	3
6	Characteristic of relations with energy consumers	3

7.	Participation of district heating company in specific programs	4
8.	Financial stability of a company	4

Each criterion is valued on five levels - from -2 to +2.
Valuation of significance is a subjective process. It has to be performed by the experts or preferably by a group of experts of the considered fields. At the same the criteria are risk factor during the project implementation.

Volume of investments into energy efficiency increase.

Size of investments into previously performed projects varies. In order to perform he analysis of investments, it is not enough to analyze the absolute value of the investment. Analysis of border values is the basis of the benchmarking method. In this case it is search of the optimal value between two values:

- indicator of specific investment Ls per resident or per ton of output (Ls/res or Ls/t output);
- investment efficiency. Ls/t CO2 reduction

In order to define necessity of previously done investments and to compare the realized projects, the optimal investments are defined for each project. Previous experience shows that rate of energy efficiency increase slows with the increase of investment.

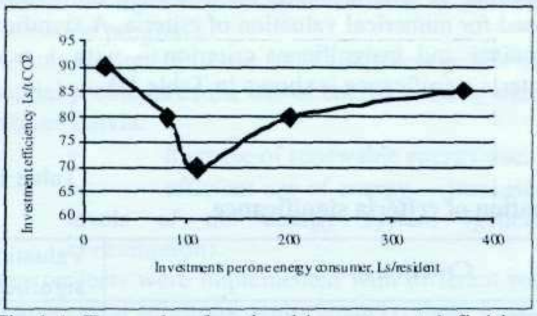


Fig.1.1. Example of optimal investment definition

Valuation of the performed reconstruction project

Analysis of implemented energy efficiency projects lets us valuate benefits and losses, and comprehend the obtained results. Before reconstruction stage boiler house operation analysis on the Figure 1.2 illustrates the above stated. There is a high data dispersion observed. Natural gas consumption data could be correlated tighter with ambient temperature data. For example, at the ambient temperature of 0°C natural gas consumption in one case was 3000 m^3/day, in the other case - 6000 m^3/day. This implies that heat energy generation process

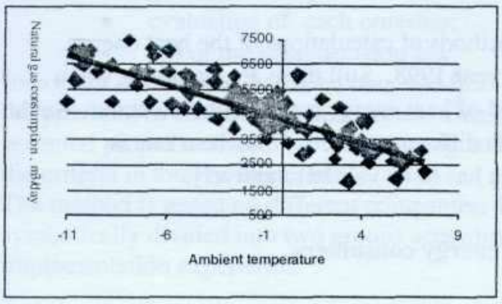


Fig. 1.2. Example of boiler room operation data analysis

regulated after the realization of the project. Each reconstruction project has to be analyzed in the same way. Indicators for projects comparison are to be found.

All energy efficiency projects that lead to the reduction of energy sources consumption are positively estimated.

Readiness of company to participate in a project is characterized with the

prepared documentation: plan, conception, and strategy of development, business plan, etc.

Energy consumer's characteristic on the current territory or company.

Energy consumer is characterized with an energy efficiency indicator that

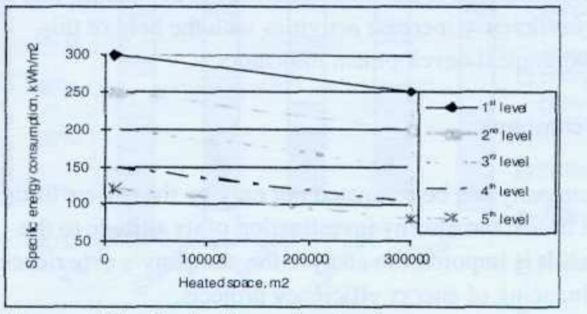


Figure 1.3. Evaluation chart of power consumer arrangement

shows the energy volume consumed by one unit (kWh/m^2). The value of an energy efficiency indicator describes not only the numerical value but also allows comparing of the

In this case number of energy consumers and their attitude to the energy efficiency activities are to be examined simultaneously. The attitude to the energy efficiency activities is described by the specific energy consumption in the project pre-realization period.
Symbolically, energy consumers can be divided into different levels. Figure 1.3 illustrates an example of the connected to the district heating system consumer division.

Energy tariff

The Cabinet of Ministers states methods of calculations of the heat energy. power and natural gas rates since year 1998. Still there are situations when digressions from the stated method of heat energy rate calculation occur. Such situations have to be valuated from different aspects. If the heat rate is calculated differently, the situation has to be valued negatively.

Characteristic of relations with energy consumers

Power and heating tariffs that are defined by the government stated methods allow evaluation of project implementation usefulness on the project pre-realization stage.

Participation of an energy source or a company in specific programs

Previous participation of the company in different projects is an important condition. It is considered using this criterion whether or not the company is located in an economically supported region or whether or not there are any specific environmental conditions. It is possible to define the companies that especially require energy efficiency increase activities with the help of this criterion and based on economical development indicators.

Financial stability of a company

Financial stability of a company can be estimated not only by the review of its credit liability and credit limits, but also by investigation of its attitude to the energy service companies. It is important to analyze the company's experience in implementation and financing of energy efficiency projects.

1.3. Information proceeding methods

The method is approbated in order to estimate the readiness of several companies to implement the woodchip project in different district heating companies.
When the criteria significance has been estimated and numerical considerations were evaluated, the mathematical calculations of the variants (companies) can proceeded.
The are three types of approach to the decision making in the calculations:

- general assessment;
- evaluation of each criterion;
- 2/3 of the ideal decision law.

Important information has been obtained from the mathematical proceeding of the provided in the questionnaire forms. This information allows comparison of potential projects, detection of their strong and weak points, and comparison of the criteria in total or separately.
The method is tested on different companies. These companies were symbolically divided into two groups according to the energy efficiency implementation experience.

1st group: Successfully implemented energy efficiency projects in the framework of different programs.
2nd group: Energy efficiency projects planned to be realized in the nearest future.
The results of the last project's usefulness research are illustrated on the Figure 1.4.

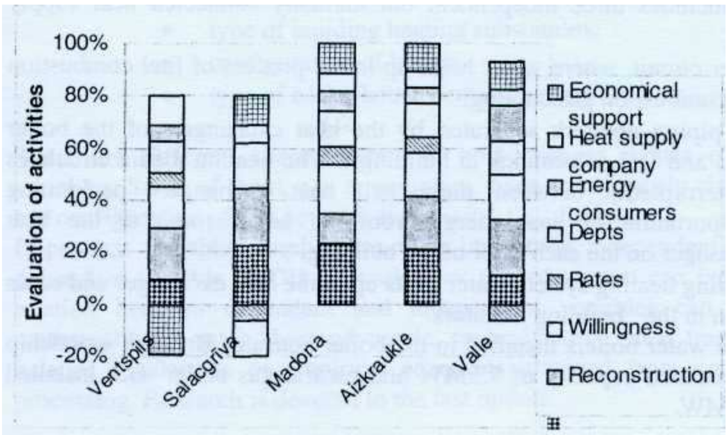


Fig. 1.4. Summary of company's willingness evaluation

2. Biofuel district heating system operation analysis experimental data proceeding

Many boiler houses have been reconstructed in municipalities of Latvia. In these boiler houses fossil fuel is replaced by wood chips. The boiler houses are connected to the district heating system and supply dwelling houses and public use buildings with heating energy. Energy consumption in the buildings depends on different factors. Some of these factors are possible to identify and influence by increasing energy efficiency and by optimization of operation mode changing, some of them are not.

At the same time another two elements of heat supply system - energy generation and heat transporation system - are also dependant on some of its operation parameters. Operation efficiency of energy transportation system depends on each of the elements of the system separately and on all of them together. The current operation indicators have to be analyzed and estimated in order to increase energy efficiency of the energy transportation system. Only then the optimization of the operation mode can be considered. Broceni town district heating (DH) system was selected as the research object. Long term heat supply system operation parameter measurement was performed in the boiler room.

2.1. Description of the experiment

DH system measurement scheme is composed taking into consideration the necessity to reduce the variable value of the system operation optimization. The system includes three independent but mutually connected heat supply circuits:

- boiler circuit, where water heats up in the process of fuel combustion and combustion gas cooling;
- DH piping network separated by the heat exchangers of the boiler room and DH substations in buildings. The heating media circulates uninterruptedly between these two heat exchangers performing transportation of heat energy from the boiler room to the heat exchanger on the each floor of the building;
- building heating system water heats up in the heat exchanger and cools down in the building radiators.

There are two water boilers installed in the boiler house of Broceni: woodchip boiler with installed capacity of 7,5MW and natural gas boiler with installed capacity of 5MW.

2.2 Correlation analysis of Brocenu district heating system parameters

2.2.1. Operation parameters of district heating system

District heating system is a complex and integrated system of technical elements created to ensure safe and stable heat consumption for the users. System consists of energy source, energy transportation and distribution systems. There are vast amounts of parameters to determine system itself and its working condition.
As parameters of DH system both thermodynamic (temperature, pressure, flow rate etc.) and technological solutions can be used. These parameters can be put into two groups:

- independent;
- dependent.

As independent parameters we can state those which are not dependant each from other and which values can change during the system operation [3,4]:

- heat load;
- flow temperature of DH network;
- return temperature of DH network;
- flow temperature of TW network;
- flow temperature of Heating network (secondary circuit);
- flow temperature of DH system;
- configuration of DH system;
- pressure drop of DH network:
- heat loss in DH network;
- type of building heating substations:
- configuration of boiler;
- type of boiler house heat exchanger

There are different characteristics of how changes values of independent variables. Some of them, e.g. temperature, have continuously changing nature, but configuration of DH network is constant, i.e., discrete. Dependant variables surely have their impact on independent variables. As dependant variable of DH network flow rate of system can be used. Mutual relation between dependent and independent variables can be described mathematically using thermodynamic, hydrodynamic, heat transfer and heat balance regularities or empirical equations obtained from analysis of data processing. Research is devoted to the last option.

There are a lot of independent variables which amount impairs our ability to analyse system operation fully However, if the existent system is researched and analyzed, it becomes clearly seen that the number of parameters reduced being substituted with the particular values that are typical for the investigated system.
Our task determines that independent variables can be those, which describe:

- system overall operation;
- operation of system components (energy source, DH piping network, consumer);
- operation of separate components of system

Due to that correlation of all these variables creates a complicated equation system and analysis of it is time consuming process, there are simpler district heating system analysis methods introduced in the research. It is proposed to obtain empirical correlations of the heat network operation characteristics.

2.2.2. One factor linear models

The aim of this thesis is to find a connection between system parameters and one-factor linear models by performing correlation analysis in order to select a type of regression equation.
Correlation analysis investigates mutual influence of several random variables and defines consistency of stochastic dependence for these variables.
The link consistency between independent and dependent variables is valuated by correlation quotient. In the case of one factor mathematical model Pirson equation can be used (2.1)

$$r = \frac{\sum_{i=1}^{m}(x_i - x)(y_i - y)}{(m-1)S_x * S_y}, \tag{2.1}$$

where

x_i, y_i	-	independent and their corresponding dependant variables;
x, y	-	average values of variables
S_x, S_y	-	value dispersion.

In the case of multiple correlation, correlation quotient R is used. It cannot be statistically evaluated but we use it as indirect parameter of regression equation suitability index. For valuation in non-linear regression instead of R value.

correlation ratio is used as it has he same meaning as R in linear correlation. Correlation ratio characterizes grouping of the results around the line of nonlinear regression. Correlation quotient evaluates how precise are mathematical models that characterize correlation consistency.

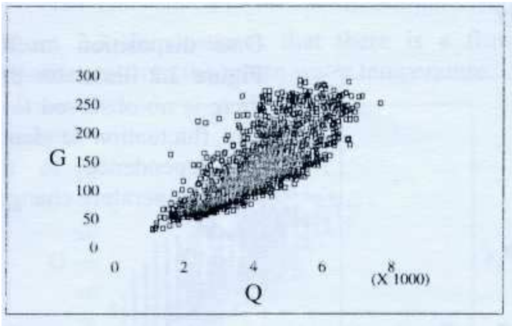


Fig. 2.1 DH network flow rate depending on heat load

2.2.3. Data correlation analysis

To analyse operation of Broceni DH system and its data one factor linear models were used together with the following independent parameters:

- heat load of boiler house Q, MW;
- DH network flow temperature ti, °C;
- DH network return temperature t_2. °C.

DH network flow rate G, m^3/h is the dependent variable parameter. Figures 2.1, 2.2. and 2.3 illustrate its dependence from heat load Q, flow t_1, and return t_2 temperature fluctuations.
Large data dispersion influenced by several independent parameters is observed and in this case one factor linear models can describe tendency of value fluctuations depending on one factor only.
Figure 2.1 illustrates that network flow rate fluctuation tendency depends on the source heat load.
Flow rate fluctuation is described by linear equations obtained from the results of experimental data correlation analysis. The mathematical correlation of the flow rate dependence from the source heat load is the following:

$$\boldsymbol{G} = -4{,}72 + 0{,}0365 * \boldsymbol{Q}\text{ , m}^3\text{/h,} \quad (2.2)$$

where

Q - heat source load, kW.

The calculated correlation quotient R = 0,77 describes the relation among the reviewed values as satisfactorily.

Data disposition on the Figure 2.2 illustrates that there is no observed flow rate fluctuation tendency on dependence to the flow temperature change.

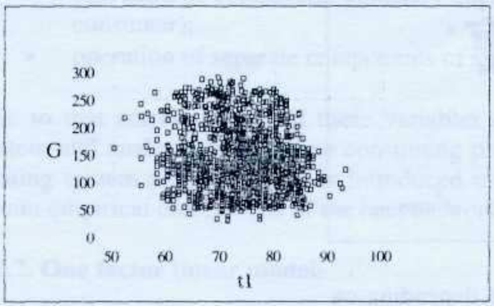


Fig. 2.2. DH network flow rate depending on flow temperature

The following empirical equation obtained as a result of data correlation analysis illustrates the dependence of the flow rate on DH network water flow temperature tl:

$$\boldsymbol{G} = 214{,}4 - 0{,}952 * t1\text{ , m3/h,} \quad (2.3)$$

where

t_1 - flow temperature, °C.

The calculated correlation quotient R = 0,11 defines that there is no observed correlation between the values and the equation cannot be used for calculations. The following equation describes flow rate in dependence to the return water temperature t_2:

$$G = -264{,}2 + 8{,}53 * t2\text{. m3/h.} \quad (2.4)$$

where

t_2 - return temperature. °C.

The calculated correlation quotient R = 0, 69 defines that there is sufficient correlation between the values.

Figure 2.3 demonstrates that there is a flow rate fluctuation tendency in dependence from the return water temperature.

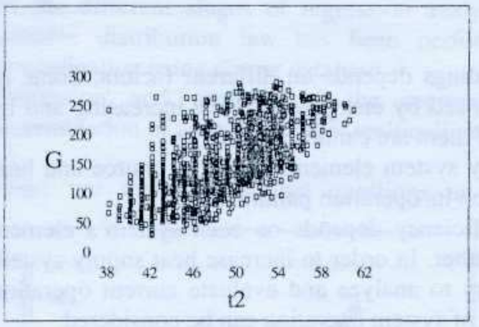


Fig. 2.3 DH network water flow rate depending on network water return temperature

Flow rate fluctuation in dependence of network water temperature difference $\Delta t = t_1 - t_2$ is observed in the process of development of a valid multifunctional regression equation. Value changes are observed on the Figure 2.4.

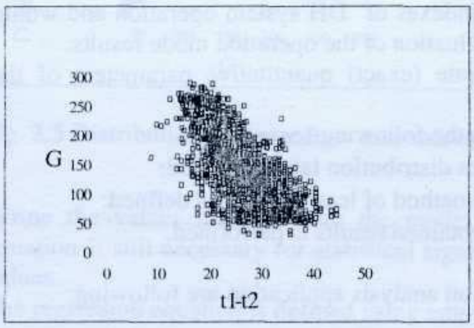


Fig. 2.4 Flow rate depending on flow and return water temperature difference

Figure 2.4 illustrates the tendency of temperature difference increase in accordance to the DH network water flow reduction. The fluctuation nature is based on the physical processes nature that occurs in the heat supply systems. According to the correlation analysis the correlation quotient R = 0,65 and there is correlation observed between the values. .

The following fact was stated as a result of data set analysis performed in the research: dependent variable quantity is network flow rate and it is related to the heat load and network water temperature difference. The empirical modelused in the following multiple-factor regression analysis is

$$G = f(Q, \Delta t) \qquad (2.5)$$

2.3. Regression analysis of biofuel (wood chips) district heating system boiler house empirical data.

Heat energy consumption in buildings depends on different factors. Some of them can be identified and influenced by energy efficiency increasing and by operation mode changing; some of them are cannot.
There are two another heat supply system elements - energy source and heat transmission system) that depend on its operation parameters.
Heat supply system operation efficiency depends on each system's element separately and on all of them together. In order to increase heat supply system operation efficiency it is necessary to analyze and evaluate current operation indicators. Only then optimization of system operation can be considered.

2.3.1. Method of analysis

The aim of the research is to obtain a multiple factor empirical equation that would quantitatively describe the indexes of DH system operation and would serve as a basis for forecast and evaluation of the operation mode results.
Regression analysis defines accurate (exact) quantitative parameters of the random variety changes Regression analysis is performed is the following sequence:

- dependent variable changes distribution law is verified;
- regression equation using method of least squares is defined;
- statistical analysis of the obtained results is performed.

The main conditions of the regression analysis application are following:

Application of the regression analysis is correct if the dependent variable (network water flow) comply with the normal distribution law. This requirement does not apply to independent variables. The above stated means that the analysis starts with the determination of variable distribution. The analysis can be continued only if the distribution complies with the normal distribution law. Verification of distribution law was performed for analyzed data set m = 1690. The data defines the indicators of heat supply system operation. Distribution of the dependent variable is shown on the Figure 2.5. Normal distribution law on the logarithmic coordinate is displayed with a line. As it is illustrated on the Figure 2.5 the analyzed data is evently distributed along the line. A little decline is noticeable at small values. It means that the distribution is approximate to the normal distribution law and the regression analysis application is reasonable.

Verification of the regression analysis correct application has been performed on the different stages of regression analysis. For example, verification of variable distribution law has been performed before regression equation determination using output database.

Derivation and analysis of the regression equation is necessary for determination of autocorrelation, multicollinearity and heteroscedasticity.

There are many significant questions to be solved when developing an empirical model as a regression equation. You have to know whether all independent variables that describe the observed phenomenon are included in the model and whether there are any odd and insignificant variables that make the model unnecessary complicated. The questions are partially answered by the previously performed data correlation analysis. They helped to define the values included into the model. Processes describing regression equation is still necessary for statistical significance evaluation of the included values.

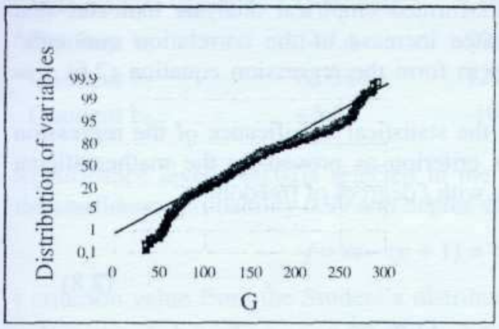


Fig. 2.5 Distribution of water flow rate values.

The regression equation is defined using empirical data:

$$y = b_0 + b_1x_1 + b_2x_2 + ... + bx = b_0 + \sum_{i=1}^{n} b_i x_i, \qquad (2.6)$$

where

y	value of the variable:
b_0	free (absolute) term of the regression equation;
$b_1 ... b_n$ -	regression equation quotients;
$x_1 ... x_n$, -	independent variables.

Significance of the quotients is evaluated. Thus, only the factors that are significant for heat supply system operation remain in the equation. Accuracy of the regression equation can be increased by including effects of factor's second and third order interaction term and thereby by forming an extended equation. Extended regression equation

$$y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i,j=0}^{n} b_{i,j} x_i x_j , \quad (2.7)$$

where

b_{ij} quotient of the second order interaction term factor;

$X_i X_j$ - second order interaction term factor.

The equation becomes more complicated and less practically applicable when the number of terms increases. Performed empirical analysis indicates that extended equations do not guarantee increase of the correlation quotients' value. Because of his the decision to form the regression equation (2.6) was made.

The *t* criterion is used to evaluate the statistical significance of the regression equation quotients $b_0 \ldots b_n$. This criterion as proved by the mathematician J.Bartlets has Student's distribution with/degrees of freedom.

$$f = m - (n + 1), \quad (2.8)$$

where

m - volume of empirical data set;

n - number of independent variables in the regression equation. In order to perform the evaluation computer calculated *t* criterion of each criterion is compared with the t_{tab} value. This value is found in the Student's distribution tables relatively to the selected significance level *P* and *f* degrees of freedom. *P* = 0,01 significance level with applicable 1- *P* = 0,99 confidence probability is used in the power engineering data proceeding. If the evaluated quotient meets the condition of $|t| > t_{tab}$, then it considered as significant and stays in the regression equation. If not, the term gets excluded form the equation and the analysis is to be performed again until all the residual quotients are defined as significant.

The derived regression equation is the mathematical model of the analyzed phenomenon. This model also has to be estimated. The estimation is performed applying dispersion analysis Fisher criterion.

2.3.2. Empirical data analysis and verification

The following factors are observed in the empirical data regression analysis:

- heat load, kW;
- flow and return temperature difference, °C.

Analyzed data set is *m* = 1690. It represents operation data of the local authority district heating system for 4 heating seasons. Regression equation quotient values and their statistical evaluation are shown in the table 2.1.

Table 2.1

Regression equation quotient values and their statistical evaluation

Independent variables	Quotients	t statistics	P value
Constant b_0	149,4	80,2	0,0000
Quotient b_1	0,0344	127,4	0,0000
Quotient b_2	-5,62	-104,9	0,0000

Significance level P=0,01 is selected in the data proceeding. It complies with the confidence probability 0.99 and degree of freedom is

$$f = m-(n+1) = 1690-(2+1) = 1687.$$

t criterion value from the Student's distribution tables that is applicable to the values stated above is t_{tah} = 3,09. Table 2.1 illustrates that in all cases the [*t*] > t_{tab} condition is met. This implies that all the parameters are significant and stay in the equation.

2.3.3. Obtained equation

An equation that defines water flow in the heat supply system is obtained as a result of the research based on the realized modes during 4 heating seasons:

$$G= 149,4+0,0344Q-5,62(t_1-t_2) \quad m^3/h \qquad (2.9)$$

The R^2 value obtained as a result of empirical model data statistical proceeding is 0,946. This implies that the developed model (2.9) illustrates 94,6 % of the analyzed modes of the network water flow changes. The rest 5,4 % are referable to the not included into the equation or not defined independent variables or to the effect of interaction of the independent variables.

Verification of the equation (6) adequacy is performed using Fisher's criterion. The value obtained by performing dispersion analysis using computer utility is F = 14680. The obtained value is compared with the tabulated value of the criterion, which is defined using the following degrees of freedom values

$$F_1 = m-l = 1690 - 1 = 1689 \text{ and } f_2 = m - n = 1690 - 2 = 1688$$

Tabulated value of the Fisher's criterion is F_{tab} - 1,0. Obviously, the $F > F_{tab}$, condition is met and this implies that the equation (6) is adequate and is applicable to the analyzed data description in their change limits:

- heating system load Q from 1000 to 7500 , kW;
- network water flow and return temperature difference Δt from 10 to 45,°C.

The observed changes of other parameters in the analyzed data set:

- network water flow G no 35 to 295 . m^3/h:
- water flow temperature t_1 from 50 to 95 , °C;
- water return temperature t_2 from 38 to 62 , °C;

2.3.4. Verification of empirical equation correctness

Verification of the obtained empirical equation correctness is performed using the positive experience obtained from the analysis of operation parameters of separate heat supply system elements.
Autocorrelation verification, DW criterion is defined using Durbin -Watson test in the processes of data statistical proceeding and data analysis. Its value is approximate to 1,4 value. This implies that there is no significant autocorrelation residual and the value evaluations made during the analysis with the method of least squares were not contorted.
Multicollinearity verification. The verification has been performed using the analysis of the regression equation calculated quotient correlation matrix illustrated in the Table 2.2.

Table 2.2.

Regression equation quotient correlation matrix

Quotients	b_1	b_2
b_1	1,0	0,0734
b_2	0,0734	1,0

The analysis of the Regression equation quotient correlation matrix indicates that the correlation between the quotients and thereby between the independent variables is insignificant. This fact is indicated by the small values of the correlation quotient illustrated in the Table 2.2. There are no observed values higher than 0,5 and therefore the quotient evaluation is correct.

Heteroscedasticity verification is performed by graphically verifying the residual distribution according to the forecasted energy consumption value and several factors. The residual distribution is illustrated on the Figures 2.7 and 2.8.

It can be observed that data set does not have a significant residual distribution changes, as well as changes related to the heat supply system load. A research of the residual distribution according to the other factors was also made. The conclusion in all the cases is that heteroscedasticity is not observed and the standard mistake is defined correct.

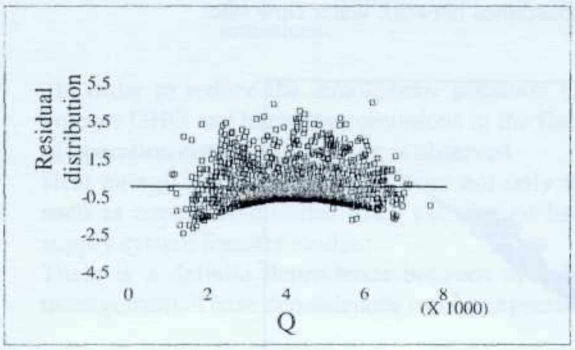


Fig. 2.7 Residual distribution depending on heat load

One of the types of regression equation verification is related to the verification of the sign of its term. It is related also to the whether or not there is a logical explanation of the definite changes occurred in the equation in terms of the physical meaning of the described processes.

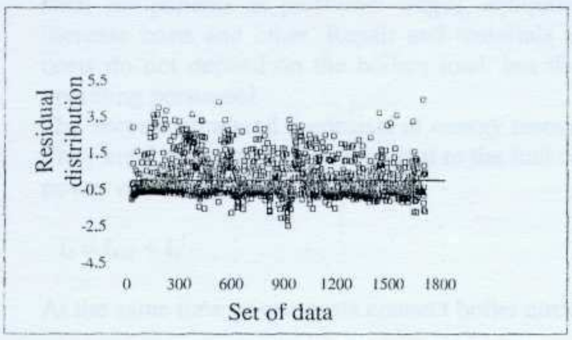


Fig. 2.8 Residual distribution for set of data

The figure illustrates that water flow rate increases at the load increase and temperature difference decrease. The visual tendency agrees with the sign of the observed factors in the regression equation (2.9) and can be logically explained. For verification of the empirical model adequacy empirical and calculated data are compared. Data comparison is illustrated on the Figure 2.10.

As figure 2.10 shows there is a good correlation exists between both data sets in the middle area of the flow rate change range from 90 to 190 m^3/h. The plotted points would lie directly on the depicted line in case if calculated values exactly matched the measurement results. There is a high plotted point scatter observed at the low and high values of the flow rate.

Evaluation of the data subjected to the statistical analysis. In the process of the regression analysis correctness verifications and verifications about possibility to proceed to the next stage were made on the each step of it.

The result of the regression analysis was evaluated as an empirical model of regression equation (2.9) that describes network water flow rate:

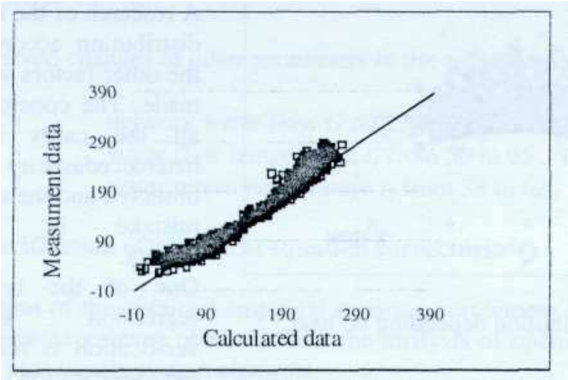


Fig. 2.10 Comparison of network water flow rate empirical and measurement data

3. Optimization of district heating system operation

3.1. Optimization tasks of district heating system operation

Management optimization shall ensure the operation of different sectors of national economy in order to achieve the maximal possible effects. There are three main tasks can be defined if this principle is applied to the power engineering sector:

1. Minimization of total fuel consumption;
2. Minimization of overall costs (in terms of money):
3. Minimization of total GHG and hazardous emissions.

In order to reduce the atmospheric pollution it is necessary to minimize the volume GHG and hazardous emissions in the flue gas. In the thesis the problem of operation costs minimization is observed.

Heat energy generation process does not only depend on the external factors such as consumer-installed load, but also on heat energy generation and heat supply system transfer modes.

There is a definite dependence between operation costs I and system mode management. These dependences can be expressed as:

$$I = I_o + I_s , \tag{3.1}$$

where

I - operation costs,

I_o - controllable costs,

I_s - energy resource costs.

The first summand is almost similar to the system operation mode. It includes such components as personnel wages, equipment reliability costs, efficiency increase costs and other. Repair and materials are also included. Controllable costs do not depend on the boilers load, but depends on the operation of the operating personnel.

The second summand I_s consists of energy resource costs or decontrolled costs. They are formed by the costs related to the fuel costs and to the pump operation power costs.

$$I_s = I_{kur} + I_e \tag{3.2}$$

At the same time power costs connect boiler circuit with the pump operation

$$I_e = I_k + I_t \qquad (3.3)$$

Fuel costs depend on the boiler operation mode and its parameters. Different types of boiler have different efficiency factors, which depend on the load mode. This implies that consumed fuel potential is defined with the following relation

$$Q_{kurj} = Q_j / \eta_k \qquad (3.4)$$

Total load of heat supply system Q_j is defined by the heat energy consumer and heat transfer losses. For the general case the following power balance for system operation in definite time T can be composed:

$$\sum_{i=1}^{n} Q_i - Q_S - \Delta Q_S = 0, \qquad (3.5)$$

where

Q_i - i-source (boiler) heat load for the time x , MW;

Q_S - total heat consumer or system heat load for the same time T, MW;

ΔQ_S - total heat power losses in the in the network, MW.

Total source load is

$$Q_j = \sum_{i=1}^{n} Q_i \qquad (3.6)$$

Heat loss in the network at constant water temperature (quantitative type of heat supply regulation) does not depend on the load changes, but depends only on the temperature values, pipeline location and insulation quality. Definite heat losses are added to the total consumer load. This approach is used in the following optimization model.

Fuel costs are calculated as follows

$$I_{kur} = Q_{kurj} * C_k, \quad Ls/h, \qquad (3.7)$$

where

C_k-fuel price, Ls/MWh.

Accordingly, power costs are defined with the following relation

$$I_e = (N_t + N_k)* C_e,\ Ls/h, \qquad (3.8)$$

where

C_e - electricity tariff, Ls/MWh;
N_t - pump power, MW;
N_k - boiler circuit pump power, MW.

It is clear from the above stated that optimization task includes also minimization of the energy source I_s, This task, in turn, consists of two subtasks:

- fuel costs minimization;
- electricity costs minimization.

Performing boiler house heat load economical distribution between two different boilers of a separate boiler house first subtask can solve. That will guarantee minimal fuel consumption and. consequently, minimal fuel costs. Mathematically this condition can be expressed as:

$$\Delta I_{kur} = \min\left[\sum_{i=1}^{n} C_k * B_i * Q_z^d\right],\ \text{Ls/h}, \qquad (3.9)$$

where

C - fuel price, Ls/MWh;

B_i fuel consumption, kg/s;
Q_Z^dfuel lower energy volume, kJ/kg.

3.2. Minimization of heat energy generation costs

The goal function of optimization task is defined with the equation (3.9). as it can be seen from the equation, minimal costs are defined by independent from the load and constant values such as fuel lower energy volume, fuel price, and variable value such as fuel combustion. Fuel combustion depends on the boiler energy efficiency and on the load distribution between the boilers.
All the above stated means that optimization task solution has to include not only cost factors, but also economic indicators of boiler operation.
The main indicator of the boiler equipment economical mode is efficiency factor. Its value depends on:

- heat load;
- technical condition:
- parameters of heating media;
- fuel type;
- operation modes etc.

Boiler test data is used in the research. The results of the test are illustrated on the Figures 3.1 and 3.2. Equations that are applicable to the efficiency factor calculation at different loads are shown. Correlation quotients of the data describing equations are high.

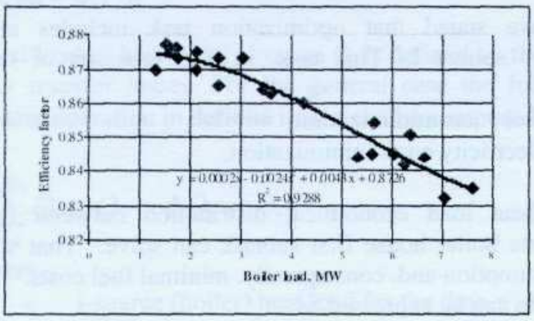


Fig. 3.1 Wood chips boiler efficiency factor depending on heat load

Two values have to be considered for boiler operation mode. They are fuel specific costs i_k, Ls/MWh and relative fuel cost changes ε_k , Ls/MWh. Both indicators have the same unit measure but their physical meaning is different. Fuel specific costs are costs per power unit at different boiler loads. Specific fuel consumption would be applicable to the boiler fuel consumption. Relative fuel cost changes show the change (increase) of the costs per one power unit.

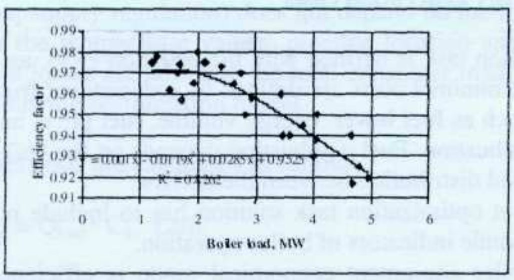


Fig. 3.2. Gas boiler efficiency factor depending on heat load

The observed method is applicable to the operation optimization of such woodchip and gas boilers, the efficiency factor of which is illustrated on Figures 3.1 and 3.2. Fuel cost curves for boilers are calculated considering the woodchip price of 5 Ls/MWh and gas price of 8,6 Ls/MWh or 80 Ls/1000 m^3. Fuel costs characteristics are shown on the Figure 3.3. The illustration shows that gas boiler fuel costs are higher at all load range than woodchip boiler costs. It is clearly observed even though the gas boiler efficiency factor is higher than woodchip boiler efficiency factor at all load range. Wood fuel boiler efficiency factors are low and the costs may even out

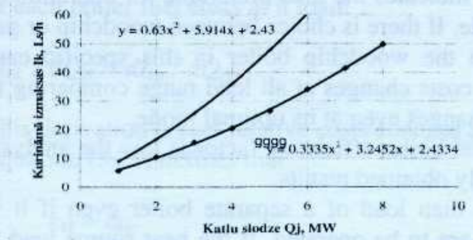


Fig. 3.3 Fuel costs changes according to the boiler load

fact that wood fuel is cheaper. In case of gas fuel the costs may be lower. For the observed boilers, as it is seen on the Figure 3.3, fuel costs are approximately similar in the case if woodchip boiler load is 7,5 MW gas boiler load is close to 5 MW.

Mathematical equations defining the curves showed on the figure 3.3 were found using correlation analysis. These equations are necessary to estimate i_k and e_k indicators.

Fuel costs in the case of woodchip fuel are defined as

$$I_{kš} = 0,333 * Q^2_{jš} + 3.245 * Q_{jš} + 2,433. \qquad (3.10)$$

In the case of gas fuel the costs are calculated with the following equation:

$$I_{kg} = Q,63 * Q_{2jg} + 5,914 * Q_{jg} + 2,43. \qquad (3.11)$$

Equations for definition of fuel specific and relative costs changes for woodchip and gas fuel are derived using the expressions (3.10) and (3.11):

$$i_{kš} = 0,333 * Q_{jš} + 2,433/Q_{jš} + 3.245 \qquad (3.12)$$

$$i_{kg} = 0.63 * Q_{jg} + 2,43/Q_{jg} + 5,914 \qquad (3.13)$$

$$\varepsilon_{kš} = 0.666 * Q_{jš} + 3,245 \qquad (3.14)$$

$$\varepsilon_{kg} = 1,26 * Q_{jg} + 5,914 \qquad (3.15)$$

Graphical interpretation of the equations (3.12...3.15) is shown on the Figure 3.4.

Figure 3.4 illustrates that woodchip boiler optimal load is approximately 4 MW and gas boiler optimal load is 2 MW. Fuel costs per power unit are minimal at these loads. The costs will rise regardless of whether the loads raise or decrease. As it was stated above fuel relative costs changes indicator is used for the mode indication. The analysis indicates the load preferable for operation of each separate boiler, if it is possible. If there is choice between woodchip or gas boiler the preference is given to the woodchip boiler in this specific case because of its lower fuel specific costs changes at all load range comparing to the gas boiler fuel specific costs changes even at its optimal mode.

As it was stated above if wood fuel boiler efficiency faqjor is low the analysis results will differ from the presently obtained results.

If the heat source load is higher than load of a separate boiler even if it is higher-powered then both boilers are to be operated. If the heat source load is lower than the sum of both boilers' maximal load then it is a problem of duty (load) of each boiler.

In this time the optimization goal is to define total operation modes of the two boilers. Total source load Q^j is covered at these modes with the minimal costs I^$_k$ If it is necessary to operate the both boilers and load raises then the equation about the choice of the boiler to be additionally loaded. This task can be described as a necessity to determine the goal (efficiency) function minimum.

$$I_{\Sigma k} = I_{k\check{s}} + I_{kg} \rightarrow min. \qquad (3.16)$$

at following condition

$$Q_{j\check{s}} + Q_{jg} = Q_{\Sigma j} \qquad (3.17)$$

One boiler's load, for example, woodchip boiler's, is considered as an independent variable and fuel costs derivative is equated as zero for function minimum determination:

$$dI_{\Sigma k} / dQ_{\Sigma j} = dI_{k\check{s}} / dQ_{j\check{s}} + dI_{kg} / dQ_{jg} = 0. \qquad (4.20)$$

Using total load equality condition for the defined Q_{Σ} and considering auxiliary function

$$Q_{jg} = Q_{\sum j} - Q_{j\check{s}},$$

then

$$dI_{kg} / dQ_{j\check{s}} = dI_{kg} / dQ_{jg} * dQ_{jg} / dQ_{j\check{s}} = dI_{kg} dQ_{jg} * d(Q_{\sum j} - Q_{j\check{s}}) / dQ_{j\check{s}} = -dIdQ_{jg} . (3.19)$$

Thie implies that

$$dI / dQ_{j\check{s}} - dI_{kg} / dQ_{jg} = 0. \qquad (3.20)$$

From this appears that total fuel costs minimum condition is derivation equality of each boiler fuel costs at it load:

$$dI_{k\check{s}} / dQ_{j\check{s}} = dI_{kg} / dQ_{jg}. \qquad (3.21)$$

This derivation is fuel relative costs changes and is previously denoted as e . Equation (3.21) defines that

$$\varepsilon_{k\check{s}} = \varepsilon_{kg}. \qquad (3.22)$$

In the general case with several boilers it can be claimed that

$$\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = ... = \varepsilon_n \qquad (3.23)$$

3.3. Minimization of district heating system operation modes costs

Minimization of heat energy generation costs does not reduce the possibilities of all costs minimization. Equation (3.2) illustrates that part of the costs is related to the DH network and boiler circuit pumping costs (3.3). These costs defined by energy transfer modes, type of their regulation (e.g., quantitative or qualitative), temperature chart of network operation, temperature limitations of boiler operation, heat exchange processes in the network heat exchanger and others. Operation modes influence boiler efficiency factors and consequently fuel consumption and costs.
Costs minimization and its results are observed below.
Costs I_s, I_{kur} and I_e are defined as Ls/h in case of defined heat load Q, realization. In order to estimate system operation costs for a year the number of hours per year when the stated load is observed has to be known. The costs per year are defined with the following relations:

$$I_{sg} = \sum_{j=1}^{j=m} I_{sj} * \tau_j \text{, Ls/year,} \qquad (3.24)$$

$$I_{kurg} = \sum_{j=1}^{j=m} I_{kurj} * \tau_j \text{, Ls/year,} \tag{3.25}$$

$$I_{eg} = \sum_{j=1}^{j=m} I_{ej} * \tau_j \text{, Ls/year.} \tag{3.26}$$

where

I_{sj}, I_{kurj}, I_{ej} - total, fuel,and power costs at the Qj mode, Ls/h;

τ_j - duration of Q_j mode per year, h.

Load duration chart has to be approximated as shown at Figure 3.5 in order to define the duration of a given partial load.

Minimization of district heating system operation modes costs is performed using two different types of approach:

- analysis performance using thermodynamic, heat balance and other regularities;
- using the results of system operation data statistical analysis.

Each approach provides different type information about system operation. Using the first approach it is possible to make a model of possible system operation border modes and their realization costs and to evaluate them. Thus, it is also a chance to evaluate system operation benchmarks and to compare them with exploitation indexes. Definition of the exploitation indexes is possible operating with the results of modes statistical analysis using the empirical relations obtained from the regression analysis. Both types of approaches help to evaluate how far or close the practical operation indexes are from the designated benchmarks. The evaluation is made using operation costs Ls/year.

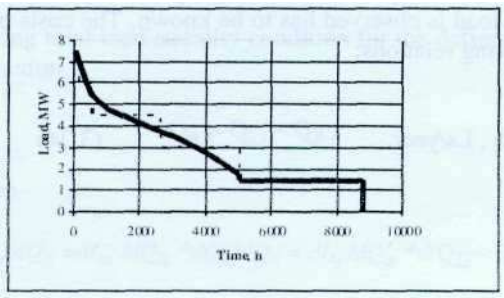


Fig. 3.5 Approximation of load duration chart

3.3.1. District heating operation optimal modes in case of quantitative or qualitative regulation

In case of quantitative regulation network water flow temperature is constant and the volume of power delivered to the customer is ensured by network flow rate regulation. Flow temperature values can differ in different systems. Normally its value varies from 95 to 120 °C. Optimization goal function can be described as

$$I_{sg} = \sum_{j=1}^{j=m} I_{sj}\left(Q_j, t_{1j}, \Delta t, \Delta t', G, G_k, C_k, C_e\right) * \tau_j\left(Q_j\right) \rightarrow \min, \text{Ls/year} \quad (3.27)$$

This expression indicates that minimal costs of system operation are formed by the minimal costs at each load I_{Sj}. Ls/h multiplied by the duration of the stated load. Duration of the load per year is defined by the load duration chart, which depends on ambient temperature changes in the current region. Optimization problem is connected to the estimation of minimal total cost value I_{sj}, Ls/h related to each load level Qj. the costs depend on the operation mode parameters and. Thus, the indicators of the mode minimal costs are the optimal values of the mode parameters.

Minimal operation costs of the heat supply system are defined not only by the network operation modes, but also by the operation modes of the boiler circuit. Both circuits are connected through the network water heat exchanger and the mutual influence of the circuits is defined and limited by the heat transition processes in the heat exchanger. Models of the modes with variable boiler circuit values are made in the research.

Minimal cost values are achieved similar to the network case - if the minimal boiler circuit flow rate is minimal. Thus, the minimal costs are achieved if there are minimal

- network flow rate;
- boiler circuit flow rate.

The constant of the minimal cost changes for the case of flow temperature (105 °C at different source loads can be described with the following equation

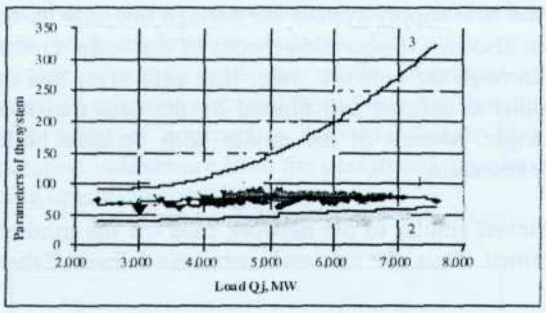
$$I_s = - 0,0943*Q^2 + 7,17*Q - 3.71 \text{ . Ls/h.} \qquad (3.28)$$

The same value at the modes where flow temperature is regulated according to the network water temperature chart can be described as

$$I_s = - 0.0892*Q^2 + 6,769*Q - 0,954, \text{ Ls/h.} \qquad (3.29)$$

3.3.2. District heating operation annual costs at average statistical modes

Comparison of system operation benchmarks with the costs average statistical operation mode is offered as a basis of heat supply system analysis method. The characteristic parameters of the system operation mode are system load, network water flow temperature t_1, network water return temperature t_2, water network flow rate G and boiler circuit flow rate G_k, water network temperature difference and others. Average statistical parameter changes are further observed. The character of the changes is shown on the Figure 3.6. The character of the system realized operation mode parameter changes indicates that there is an uncertainty observed in the selection of the parameters. The values of the flow temperature increase when the load value increases and decline after the maximal value of approximately 5 MW is reached. It is clearly seen that the highest flow temperature values are lower than the possible highest values in both quantitative and qualitative cases.



Calculation of the costs starts with the introduction of the regression equation that describes the changes of parameters. The load in the equations is in MW. For flow temperature determination the following regression equation is used

Fig. 3.6. System operation mode parameter changes

1 - network flow temperature t_1, °C;
2 - network return temperature t_2, °C;
3 - network water flow rate G, m^3/h.

$t_1 = 42{,}1 + 12{,}9 * Q_j - Q_j^2$, °C.

$$t_1, = 42{,}1 + 12{,}9 * Q_j - Q_j^2 , °C \qquad (3.30)$$

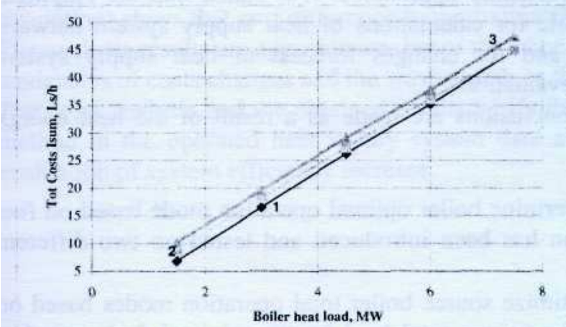
Network water return temperature is described with the equation

$$t_2 = 35 + l{,}2 * Q_j + 0{,}3 * Q_j^2, °C. \qquad (3.31)$$

Network water flow rate values are calculate using regression equation

$$G = 149{,}4 + 34{,}4 * Q_j - 5{,}62 * (t_1 - t_2), m^3/h. \qquad (3.32)$$

The observed heat supply company did not record circuit indicators during the heating season. Special measurements were required to obtain the missing data. The volume of this data is significantly smaller that the volume of the other sets of parameter data. Because of this statistical analysis for boiler circuit data was not performed and regression equations that describe the data were not derived. The data values that were obtained as a result of the analysis performed in the research were used in the calculations. The value of the water flow rate in the boiler circuit Gk was considered the same as network water flow rate G. Network water operation analysis shows that thus the conditions of heat transition in the heat exchanger at possible lowest flow rates in the boiler circuit are met.
Operation modes costs values and their changes depend on the system heat load, which is illustrated on the Figure 3.7. The costs analysis was made. The obtained results indicate the usability of the offered method in the analysis of operated heat supply system data and economical evaluation of the increase of system efficiency.
For evaluation of the real modes of the heat supply system in this research there was made a statistical analysis of parameters of three heating seasons modes. The methods of regression and



3.7. att. Total cost comparison
1 – t_1 = 105 ^{0}C; 2 – $t_1 = f(t_{out})$;
.3 – average statistical level

correlation analysis were used in this analysis.
In the process of the regression analysis correctness verifications and verifications about possibility to proceed to the next stage were made on the each step of it. The result of regression analysis was evaluated as a regression equation (3.32) that describes water flow rate. Regression equations of the other parameters were also obtained.

Conclusions:

1. The method for selection of successful energy efficiency projects in the regions of Latvia has been developed.
2. Data regression analysis is correct because the dependent variables comply with the normal distribution law.
3. Empirical model in the form of regression equation (3.32) includes the main factors that define flow rate. Its signs in the equation are logical and conform to the physical interpretation of the processes. Application of the method of least squares to the values determination is proved and these values are not distorted. It is proved by the value of DW criterion which is close to its acceptable border. Evaluation of the regression equation quotients is correct because there is no con-elation observed among them. Data evaluation standard mistake is evaluated correct because residual distribution is even according to the dependent and independent variables.
4. Method for empirical data statistical analysis of the heat supply system operation and derivation of analysis based calculation relations were introduced and practically approbated. It is stated that the empirical model is applicable for calculations of heat supply system network water flow rate and for changes forecast of heat supply system operation modes evaluation.
5. The following conclusions are made as a result of the heat energy costs analysis:

- the method to determine boiler optimal operation mode based on fuel costs minimization has been introduced and tested on two different fuel boilers:
- the method to optimize source boiler total operation modes based on the covering of the source total load by the minimal fuel costs has been introduced and approbated;

- both methods are applicable for mode optimization in terms of minimal fuel consumption , if the source is operated by the one type fuel.

6. The costs analysis for the heat supply system total operation mode has been performed using two different types of approach:

- analysis performance using thermodynamic. heat balance and other regularities if the system is quantitative or qualitative operated;
- using the results of system operation data statistical analysis.

Each approach provides different type information about system operation. Using the first approach it is possible to make a model of possible system operation border modes and their realization costs and to evaluate them. Thus, there is also a chance to evaluate system operation benchmarks and to compare them with exploitation indexes. Definition of the exploitation indexes is possible by operating with the results of modes statistical analysis using the empirical relations obtained from the regression analysis. Both types of approach help to evaluate how far or close the practical operation indexes are from the designated (marked) benchmarks. The evaluation is made using operation costs Ls/year. The system operation modes costs analysis shows that the highest costs are at the average statistical operation modes.
Operation costs in the case of this current heat supply system management are approximately 11000 Ls/year or 6.2 % higher than in the caser of qualitative regulation (the system How temperature is regulated according to the network water temperature chart). Comparison of the current operation mode costs with such mode at which flow temperature is maximal and constant (quantitative regulation) slows that cost difference is approximately 21000 Ls/year or 13 %. The analysis results are approximate, but at the same time they describe the tendencies of costs changes and the ways to reduce them. The costs analysis and the obtained results verify the usefulness of the offered method in the operated heat supply system data analysis and in economical evaluation of system efficiency increase.