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INVESTIGATION OF DISTRICT HEATING FOR RESIDENTIAL SECTOR

Summary of the Doctoral Dissertation

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This scientific work was carried out in 1999–2005 at Lithuanian Energy Institute, Laboratory of Regional Energy Development.

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INTRODUCTION

Relevance of the work. Heating of residential buildings is the largest heat consumption sector in Lithuania as well as in neighbouring countries with similar climatic conditions, where premises are typically heated nearly seven months during the year. Discussion on the energy saving in Lithuania started after restoration of independence. The first National Energy Efficiency Programme was elaborated in 1992; it was initiated by the former Ministry of Energy and adopted by the Government of Lithuanian Republic. Later National Energy Efficiency program was revised and corrected with regard to the situation in national economy and separate economic sectors and development projections.

Today the difference in heat tariffs between small towns and large cities is the largest concern. Higher heat tariffs make major social problem in small towns. It can be notified that the largest heat tariffs are formed in those regions (districts), where Gross domestic product (GDP) is the smallest one.

Though heat consumption is stabilizing, there is still large variation in relative heat consumption between different buildings, which can depend on variety of factors: the size of residential buildings and variety of construction-technical solutions, maintained inside temperature, mentality of residents and other factors. Foreign countries have statistical data collecting and summarizing systems for assessment of the impact of above factors to heat consumption in residential buildings, which are used for forecasting heat market in residential sector. There are still no detailed investigations on household heat market.

The investigations of end use in residential heat sector are important for forecasting of heat market and planning improvement of demand side. Achieved functions for heat consumption versus external and internal factors can be successfully used for revising of existing mathematical models, used in heat sector. Here one needs to have research based data not only on construction and technical characteristics of residential buildings, but also on the reaction of residents to heat tariffs, comfort level, introduction of meters and investments into improvement of household quality.

In practice it is impossible to perform energy audits of all buildings throughout the country or create overall data basis. Creating of mathematical model is one of available ways to forecast the trends of energy consumption in the buildings and evaluate former and still required investment. The analysis of heat consumption data of several years is required to avoid errors and inaccuracies. It should be performed at least for several Lithuanian towns, which differ in geographical location, number of centrally heated buildings and other factors.

Object of investigation is the end use of district heat in countries' residential sector.

Methodology of investigation. Mathematical modelling, statistical and comparative analysis.

Main goal of this work – to establish background for improvement of forecasting and planning of heat market for district heating through defining functional relations between heat consumption versus internal and external factors.

Main tasks for this work are as follows:

- Collect and systemize available data on heat consumption from district heating in residential buildings of various towns, through creating data basis for statistical analysis,
- Create mathematical model of common heat consumption in the buildings for assessment of functional relations vs. internal and external factors,
- Evaluate function between district heat and quality indicators of covering heat needs,
- Identify functions of the main exogenous criteria, defining market changes for district heat consumers,
- Perform comparative analysis for various towns and define general tendencies on heat consumption in residential sector.

Novelty of the work is investigation of main indicators, having impact to heat demand in residential sector:

- The analysis of monthly heat consumption in residential buildings on the basis of billing data between heat suppliers and consumers in several towns for the period of 3-4 was performed for the first time,
- Theoretical model was created for assessment of total heat demand for heating and preparing of hot water through minimizing the difference between actual and theoretical monthly heat consumption,
- It was suggested to use statistical values of inside temperatures of residential buildings and the ratio between the total and specific heat demand for assessment of covering heat needs (in comfort level),
- Generalization of numerical investigation results with the equations of multi-parametrical regression analysis.

Scientific and practical value of this work. Scientific value of the work – description of the heat end use from district heating in residential sector through mathematical expressions, and defining of parameters for evaluating the impact from each of investigated factors through using created mathematical model.

Practical value of this job is that after objective assessment of current heat consumption from district heating in residential buildings realistic opportunities appear for better forecasting of future consumption, evaluating factors, which do not depend on the supplier of district.

Approbation of the work – this works consists of introduction and 5 chapters. The volume of the job consists of 112 pages, including 63 figures, 23 tables and the list of 64 references.

1. OVERVIEW OF HEAT MARKET INVESTIGATIONS

The work overviews general situation in Lithuanian heat consumption market. It assesses the state of the market for district heating to residential buildings and notifies problems to be solved; the most important problems are – collecting of comprehensive statistical data on heat consumption in residential sector and ensuring normal comfort level in residential buildings.

Performed research disclosed that similar problems existed in USA and West European countries.

This work also presents short overview for modelling experience in energy sector and general equations of end use and makes the conclusion that receiving reliable investigation output for heat consumption in residential sector should be based on monthly heat consumption data and analysis of this data with mathematical model.

2. BASIC EQUATIONS AND METHODOLOGY OF HEAT DEMAND ASSESSMENT IN RESIDENTIAL SECTOR

Annual heat demand for district heat per unit of residential heated area should in general case be divided into 3 components per monthly or other time periods:

$$q_{\Sigma} = \sum_{n=1}^{12} \sum_{s=1}^{3} q_{s,n} \;; \tag{1}$$

here

q_{Σ} – annual heat demand,

$q_{s,n}$ – monthly heat demand,

indexes are:

$s = 1$ – specific demand for heating of the building (heat losses through envelope),

$s = 2$ – heat losses in the building, related to ventilating and infiltration,

$s = 3$ – heat demand for preparing of hot water,

n – addition index by months.

Total theoretical heat demand for *j* building and *n* month is estimated through equation:

$$q_{U,j,n} = \begin{cases} U_j \cdot \left(\dot{t}_{vd,j} - \dot{t}_{is,n}\right), & if \ \ t_{is,j} \le t_{sz} \\ q_{kv}, \ \ if \ t_{is,n} > t_{sz}. \end{cases}; \tag{2}$$

here

U_j – total heat demand for compensating heat losses in *j* building for one degree difference between outside and inside temperatures, W/m^2·°C,

$t_{sz} = 8$ – describes seasonal transition temperature, °C,

q_{kv} – heat demand for preparing hot water, W/m^2,

$\dot{t}_{vd,j}$ – assessment of average inside temperature for *j* building of investigated year, ºC,

$\dot{t}_{is,n}$ – average monthly outside temperature, ºC.

The assessment of heat demand during summer season uses the following equation:

$$q_{kv,j} = a_{1,j} \cdot \overline{B} \cdot \ln\left(\frac{GS_j}{A_j \cdot GSA_0}\right)^{a_2}; \tag{3}$$

here

A_j – heated area of j building, m^2,

GS_j – number of residents in j building,

$\overline{B}$ – average area of the apartment, m^2,

GSA_0 – average number of residents per unit of residential area, persons/m^2.

a_1 and a_2 – coefficients.

The function of specific heat consumption should be as follows:

$$q_{W,j,n} = \begin{cases} W_j \cdot \left(\dot{t}_{vd,j} - \dot{t}_{iš,n}\right), & if \ \dot{t}_{iš,n} \le t_{sz}, \\ 0, \ \ if \ \dot{t}_{iš,n} > t_{sz}; \end{cases} \tag{4}$$

here

W_j – relative specific heat consumption for compensating heat losses through the envelope of the building, for one degree difference between outside and inside temperatures W/m^2·°C,

$q_{w,j,n}$ – heat losses through the envelope for *j* building, W/m^2.

The function of thermal capacity vs. outside temperature is expressed through linear equation:

$$q = a \cdot t_{iš} + b. \tag{5}$$

According to norms valid in Lithuania maximal heat capacity demand is equal to heat consumption at outside temperature of -23^{0}C:

$$q_{\max} = -23 \cdot a + b. \tag{6}$$

While $q = 0$, we find average inside balance temperature t_{vd}:

$$t_{vd} = -\frac{b}{a}. \tag{7}$$

The ratio between total and specific heat consumption is the important indicator for assessment of comfort level. Such ratio would depend on the area of residential buildings. Analysis find non-dimensional indicator more appropriate:

$$K_{VD} = \frac{U \cdot W_0}{W \cdot U_0}. \tag{8}$$

Here the value of indicator K_{VD} = 1 will mean theoretical ventilating demand, estimated for changing the air inside premises 0.8 times per hour.

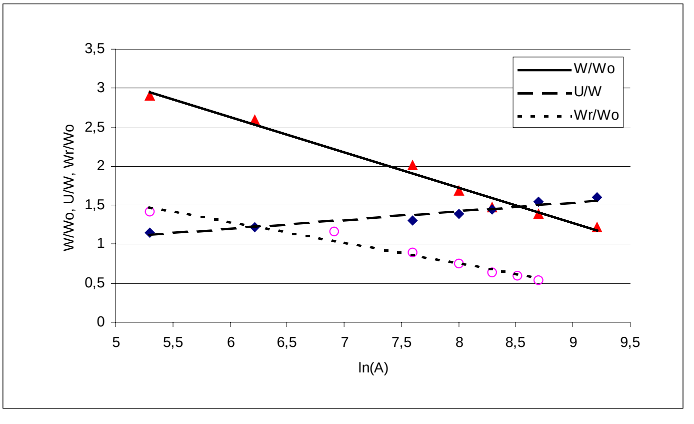

Figure 1. The function of relative specific heat demand before renovation (W/W$_0$), ratio between total and specific losses (U/W) vs. the area of the building according to the data of 1995 and specific relative heat losses through envelope after renovation (W$_r$/W$_0$)

Comparison of actual heat demand with known specific and ventilation heat losses was one of the goals of this work. The investigation data of heat losses vs. the number of floors in residential buildings was used as the comparison basis [1], and functions of relative specific and total heat losses after this assessments were estimated as follows:

$$W_j / W_0 = -0.4544 \cdot \ln(A_j) + 5.3592\,; \qquad (9)$$

$$\frac{U_j}{W_j} = 0.1144 \cdot \ln\left(A_j\right) + 0.5094\,; \qquad (10)$$

here

W_j – specific heat losses through envelope for j building, for 1^0C temperatures difference, $W/m^2 \cdot {}^0C$,

U_j – total heat consumption for compensating the losses of j building, for 1^0C difference between outside and inside temperatures, $W/m^2 \cdot {}^\circ C$,

W_0 – specific heat losses for the building of average 2000 m^2 area, for 1^0C temperatures difference $W/m^2 \cdot {}^0C$ (38.1 W/m^2 or 333.8 kWh/m^2 per annum).

For generalization of selected theoretical model we can state that the demand of any j residential building can be described with the following function vs. unknown parameters:

$$q_{U,j,n} = f(\dot{t}_{vd}, U_j, a_{1,j})\,, \qquad (11)$$

where values are defined through minimization of the functional:

$$\Phi = \frac{1}{N_{\dot{n}}(N_j - 3)} \sum_{j=1}^{N_j} \sum_{n=1}^{N_n} \left| q_{fakt,j,n} - q_{U,j,n} \right| = \mathbf{min}\,. \qquad (12)$$

3. THE INVESTIGATION OF ANNUAL HEAT CONSUMPTION IN RESIDENTIAL SECTOR

Data presented in National Energy Efficiency Programme (NEEP) are considered as the main guideline for describing the situation of heat consumption in residential sector [2].

Regressive analysis of mentioned data permitted to achieve the following functions of heat consumption vs. total area of the buildings, which were used for comparison with the results of this work:

$$q_2 = 506.83 - 34.783 \cdot \ln(A), \tag{13}$$

$$q_3 = 314.82 - 16.522 \cdot \ln(A), \tag{14}$$

$$q_4 = 185.57 - 6.1566 \cdot \ln(A), \tag{15}$$

A – total heated area of the building m^2,
q_2 – heat demand according to data in NEEP $kWh/m^2 \cdot$ annum,
q_3 – consumption level, which can be achieved with economic investment in present conditions (in relation to the consumer) $kWh/m^2 \cdot$ annum,
q_4 – minimal consumption level, reflecting maximal investment, described in NEEP $kWh/m^2 \cdot$ annum.

Difference between consumption level (q_2) according to NEEP and minimal consumption level *(q_4)* is evaluated as technical potential for improvement of energy efficiency in the buildings through implementing maximal package of energy conservation measures. Consumption level in expression q_3, is called by NEEP as economic for consumers in present conditions.

Heat was distributed according to design indicators in 1990 in Klaipėda as well as in other towns. Variation of design indicators more or less reflects construction characteristics of formed buildings. It is evident that design energy needs of the buildings were increased with regard to the worst climate conditions and enlarged assurance factor. These data are described by the following equation:

$$q_{pr} = -28.198 \cdot \ln(A) + 594.91 \,. \tag{16}$$

Development of heat consumption during 1999–2002 in residential buildings of Klaipėda are shown in Figure 2.

The process of the improvement of heat consumption efficiency is well illustrated in the function of the area of residential buildings vs. relative heat consumption (Figure 3).

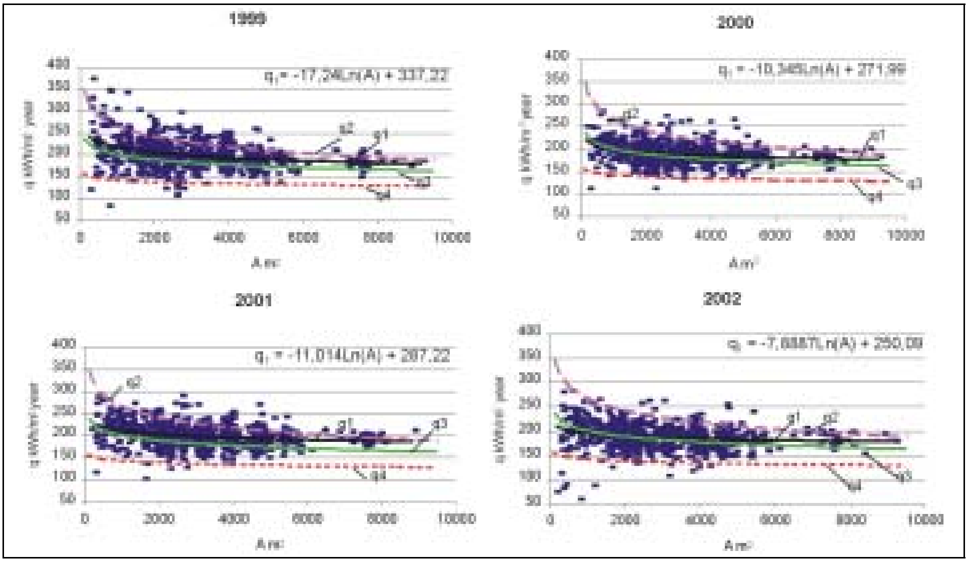

Figure 2. The function of relative heat consumption vs. buildings area in Klaipėda during 1999–2002: q_1 – average relative heat consumption according to actual consumption data, q_2 – heat demand according to data in NEEP, q_3 – economic consumption level will small investment according to NEEP, q_4 – heat demand reflecting heat losses in the buildings according to the new standards for insulation

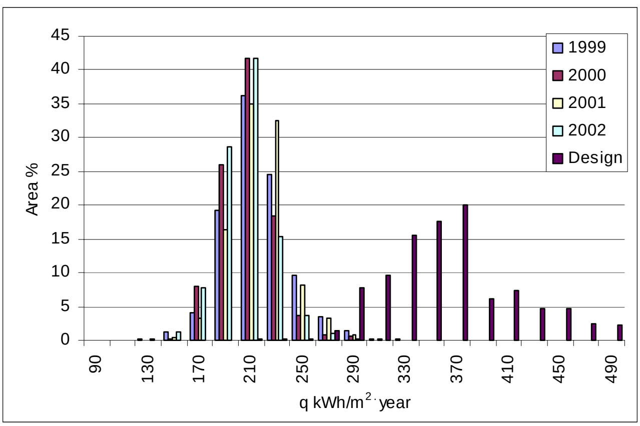

Figure 3. Function of residential area in Klaipėda vs. relative heat consumption

Such functions were defined not only for Klaipėda, but also for several small towns. Description of quantitative annual heat consumption used normal distribution function:

$$f_{\dot{q},S}(q) = \frac{1}{S\sqrt{2\pi}} e^{-\frac{(q_i - \dot{q})^2}{2 \cdot S^2}}, \tag{17}$$

here

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(q_i - \dot{q})^2} \text{ – average square deviation,} \tag{18}$$

$$\dot{q} = \frac{\sum_{i=1}^{N_q} q_i \cdot A_i}{\sum_{i}^{N} A_i}, \quad i = \overline{1, N_q}\,. \tag{19}$$

The peculiarities of normal distribution functions for investigated towns are shown in Figure 4.

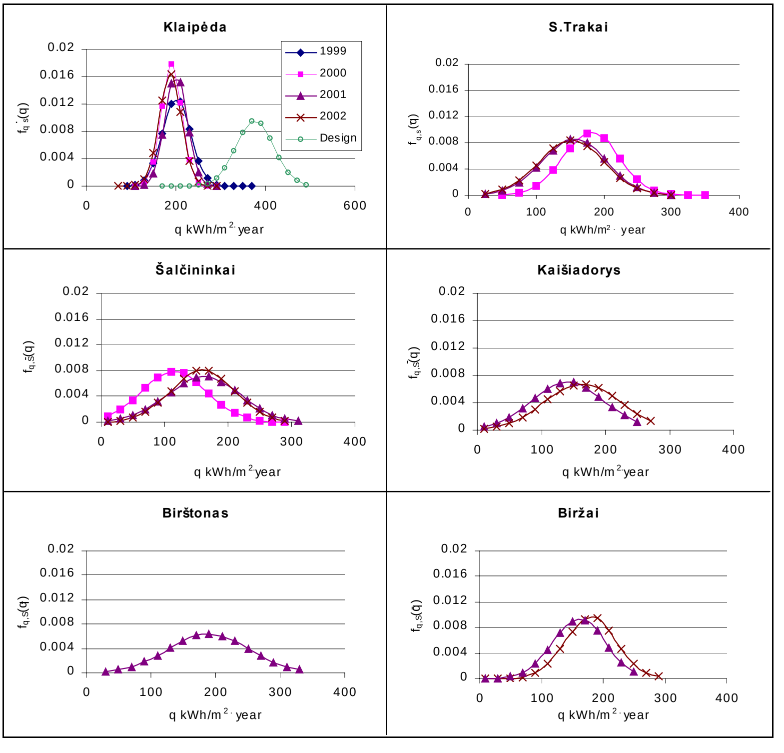

Figure 4. Normal relative function of heat consumption in Klaipėda and small towns

The values of statistical analysis for indicators $\dot{q}$ and S during investigated period are presented in Table 1.

Table 1. Statistical values of urban heat consumption $\dot{q}$ and standard deviation S

Town	Year	2000	2001	2002
Klaipėda	Set	916	908	904
	$\dot{q}$	190	200	188
	S	22	24	24
S.Trakai	Set	18	18	17
	$\dot{q}$	181	156	152
	S	42	46	48
Kaišiadorys	Set		103	108
	$\dot{q}$		142	164
	S		56	59
Šalčininkai	Set	110	125	128
	$\dot{q}$	116	161	160
	S	50	56	49
Biržai	Set		114	105
	$\dot{q}$		161	180
	S		42	41
Birštonas	Set		77	
	$\dot{q}$		189	
	S		62	

Summarizing the performed statistical analysis on heat consumption in residential sector we may come to the conclusion that heat consumption in small towns is much lower than in large ones. Lower heat consumption in small towns can’t be considered as the growth of the efficiency, since it was achieved not through improving the quality of the insulation of the buildings.

Analysis of qualitative indicators of heat demand in residential area was performed for definition of causalities for such differences.

4. INVESTIGATION OF QUALITATIVE INDICATORS OF HEAT DEMAND IN RESIDENTIAL AREA

Performed comprehensive analysis of annual heat consumption in the buildings showed just the changes of annual heat consumption and the trends during investigated period. However this data says nothing on the changes of heat consumption during the year. It is also not clear what is the impact of certain internal and external indicators.

For the purposes of this work mathematical heat demand model was created and used for investigating of heat consumption as the separate type of energy used in households. Mathematical model enables investigation of the consumption of each separate building in data basis as well as generalization of achieved results with regard to describe average heat consumption indicators of the group of investigated buildings and undergone changes. This model enabled not just theoretical description of available actual consumption data but also forecasting of future consumption. This model is based on annual heat demand. Basic equations and methodology, that make mathematical background for heat consumption, are described in Chapter 2.

4.1. Simulation of heat demand in residential buildings of Klaipėda

The outcome of analysis performed with created mathematical model for actual heat consumption in residential buildings of Klaipėda since 1999 till 2002 are shown in Figure 5. Analysis used monthly consumption data for more than 900 buildings in Klaipėda. Here we see average total heat consumption of town buildings (1), theoretical function for total (bracket line 2) and specific (dashed line 3) heat losses vs. outside temperature $t_{iš}$. The crossing point for heat demand lines (4) during heating season and axe of temperature $t_{iš}$ according to equation (2) can be interpreted as average outside temperature, at

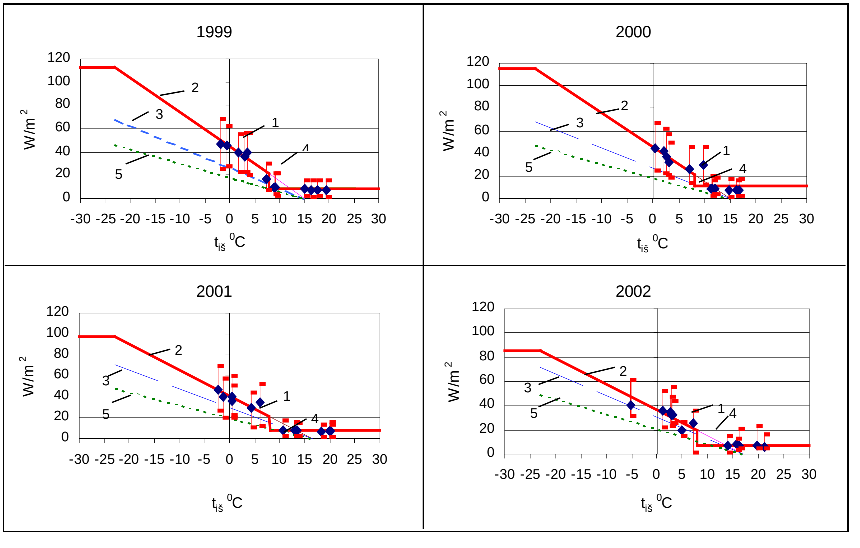

Figure 5. Monthly heat demand analysis in Klaipėda according to heat consumption data of 1999–2002

which internal heat sources should ensure standard inside temperature. On the other hand this characteristic point shows the function of heat demand vs. characteristics of outside temperature, i.e. shift towards higher temperature shows the need of residents to maintain higher inside temperature. Dotted line (5) shows specific heat demand of the buildings with envelope meeting the requirement of valid standards.

Evaluating that there was no major renovation of the buildings during investigated period performed analysis shows that heat consumption for space heating was decreasing during 1999–2000, which might be because of reduction heat consumption for ventilation needs.

Table 2. Statistical values of parameters under investigation in Klaipėda

Year	1999	2000	2001	2002
$\bar{t}_{iš}$	1.94	3.99	1.65	1.81
$\bar{t}_{vd}$	15.1	15.1	16.5	17.0
a_1	8.21	11.00	7.50	6.85
$\bar{A}$	3072	3066	3061	3064
$\bar{U}$	2.97	3.00	2.45	2.13
$\bar{W}$	1.78	1.78	1.78	1.78
$\bar{U}/\bar{W}$	1.67	1.72	1.39	1.21

The outcome of the analysis for Klaipėda showed that average balance temperature during investigated period changed from 15.1 to 17^0C (Table 2), and average heat consumption for preparing of hot water was approximately 72.7 kWh/m$^2\cdot$annum (8.3 W/m^2) during investigated period. Meanwhile the ratio between average total and specific heat consumption $\bar{U}/\bar{W}$ shows, that heat consumption for ventilation of premises could be higher than theoretically required (U_0/W_0=1.29) during 1999–2002.

4.2. Simulation of heat demand in residential buildings of small towns

For assessment of heat supply quality using created mathematical model heat consumption analysis was performed for several small towns, similar to that of Klaipėda city (Figure 6).

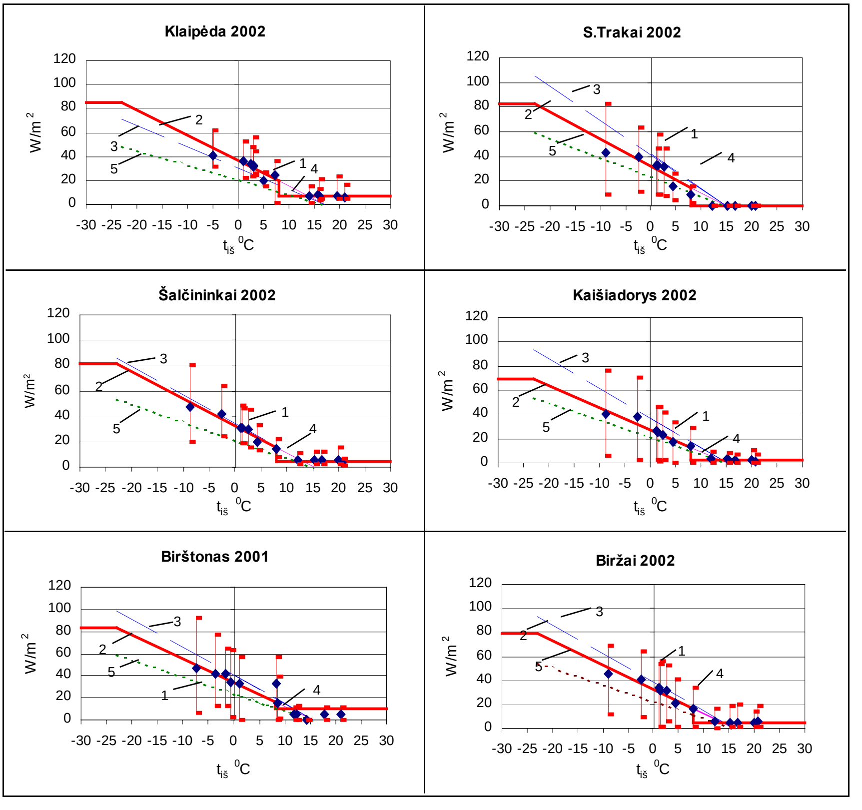

Figure 6. The functions of consumers heat demand capacity for space heating and outside temperature in small towns according to consumption data and comparison to Klaipėda data

Different from Klaipėda, total heat losses in residential buildings were equal or lower than average specific heat losses in the buildings over the country. This is a serious signal that sanitary norms inside buildings could be violated.

Small towns heat demand analysis shows that residents were restricting their needs through maintaining lower inside temperatures during several years.

4.3. Quantitative assessment of comfort level in residential buildings

Evaluating the annual as well as monthly changes in heat demand we can make justified conclusions on the changes of comfort level in residential buildings. Inside temperature of the premises is one of parameters used for assessment of comfort level. Since measured inside temperatures are not available for residential buildings, analysis was restricted with statistical values of average balance temperatures during heating season. Thus achieved results of simulation can be compared with available sparse data and data, presented by other researchers with assumption that acceptable comfort level is similar for consumers in all countries.

As the results of the analysis show, the value of average balance inside temperature during heating season was growing during investigated period in Klaipėda. With the assumption that the capacity of inside heat sources have not changed, we may come to the conclusion that average inside temperature of residential premises in Klaipėda increased during four years and comfort level improved in terms of maintaining inside temperature.

The outcome of investigation in small towns shows that the values of statistical indicators t_{vd} were changing from 15 to 16.5°C in investigated towns during various years. It would be difficult to see evident general growing or falling trend. Assuming that the capacity of inside heat sources have not changed,

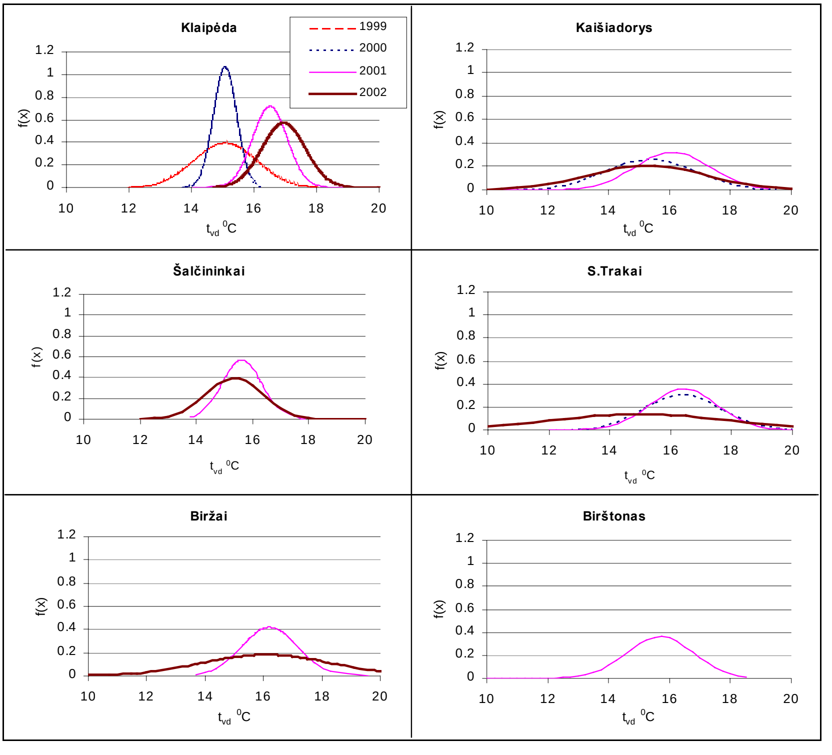

Figure 7. Normal (Gauss) distribution curves for balance temperatures of Klaipėda and small towns

we may come to the conclusion that inside temperature in residential buildings of small towns as well as comfort level in terms of maintaining inside temperature has changed insignificantly during investigated period. Larger deviation of balance inside temperature is characteristic to small towns comparing to Klaipėda (Figure 7).

Such temperature of residential premises can't be considered as meeting comfort needs.

The ratio between specific and total heat losses, expressed as non-dimensional indicator K_{VD}, can be considered as important indicator for assessment of comfort level.

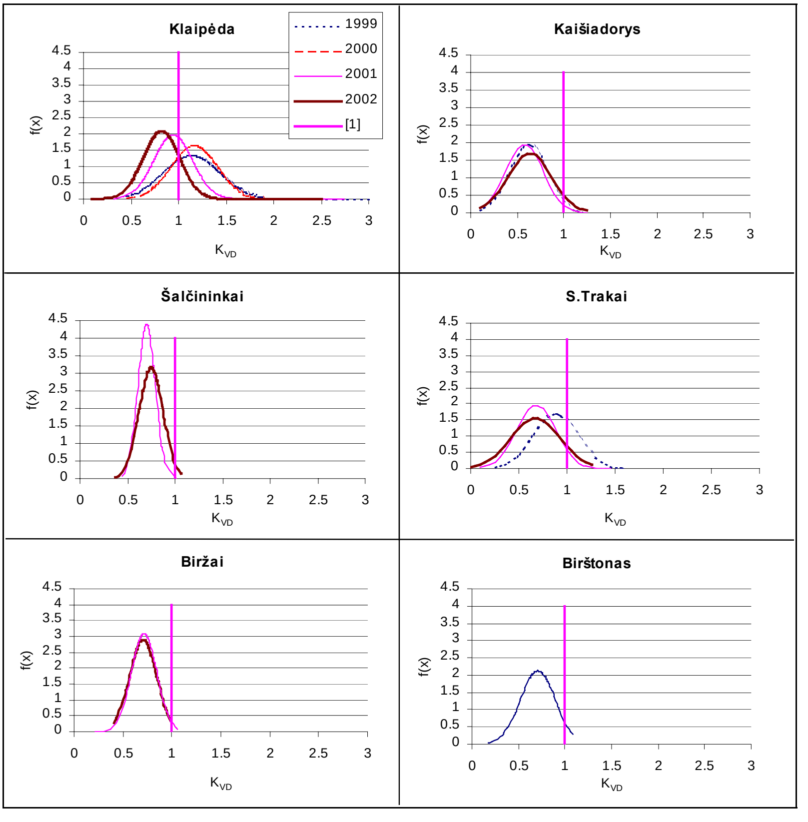

Figure 8. Normal (Gauss) distribution for total and specific losses during investigated period

Average values of theoretically estimated ratio between total and specific heat losses in small towns during 1999–2002 are clearly shifted towards lower values in comparison with value K_{VD} = 1.29, which means the requirement of the change of inside weather by 0.8 times/h.

In terms of reasonable maintaining of comfort level in residential premises this situation is similar in all small towns. This means that residents have reduced their heating needs to minimal ones or even below health and sanitary requirements because of solvency problems.

Making conditions for restoring usual comfort level in residential premises should be one of the most important priorities of state social policy in energy sector.

4.4. The impact of external indicators for covering heat needs

Most data was accumulated on residential sector and heat consumption in Klaipėda city. It would be not appropriate to make wider conclusions on heat consumption from the investigations in one single town. Data and investigation results from similar analysis in several smaller towns were used for more general conclusions.

Regardless to limited available investigation results multi-parameter functional analysis of prevailing heat demand (consumption) vs. the following parameters was performed:

- difference between inside and outside temperatures,
- period,
- heat tariff,
- size of town.

Exponential function of relative heat consumption vs. above parameters was selected for data analysis:

$$\dot{q} = q_o \cdot \prod_{i=1}^{4} K_i^{\alpha_i} ; \tag{19}$$

here

$$K_1 = (\dot{t}_{vd} - \dot{t}_{sz}) / \Delta t_{st}, \tag{20}$$

$$K_2 = year - 1998, \tag{21}$$

$$K_3 = T_{th} / 100, \tag{22}$$

$$K_4 = GS / 100000, \tag{23}$$

$\dot{t}_{vd}$ – value of inside temperature ºC,

$\dot{t}_{sz}$ – average outside temperature during heating season ºC,

T_{th} – heat tariff Lt/MWh,

GS – population of investigated towns,

Δt_{st} – normative inside temperatures (18ºC) and the difference ($\Delta t_{st} = 18.5$) of long term statistical average temperatures during heating season (-0.5ºC)

α_i – indicator defining the impact strength of investigated indicators.

Table 3. Statistical values for heat consumption functions vs. investigated factors in five towns*

$\ln(K_4)$	$\ln(K_3)$	$\ln(K_2)$	$\ln(K_1)$	$\ln(q_0)$
$\alpha_4 = 0.045$	$\alpha_3 = -0.2$	$\alpha_2 = 0.042$	$\alpha_1 = 0.072$	$\ln q_0 = 5.197$
$Sl_4 = 0.023$	$Sl_3 = 0.281$	$Sl_2 = 0.066$	$Sl_1 = 0.214$	$Sl_q = 0.122$
$r^2 = 0.664$	$S_y = 0.082$			
F = 4.93	N = 10			
$SS_{reg} = 0.132$	$SS_{resid} = 0.063$			

* The protraction of some statistical values are adequate to output indicators of standard function LINEST.

Sl_I – standard errors for coefficients α_1, α_2, α_3, α_4, $\ln q_0$,
r^2 – link coefficient, S_y – standard error for estimated lng,
F – statistics, which is used for defining the link between dependent and independent variables,
N – degrees of freedom,
SS_{reg} – regressive sum of squares; SS_{resid} – residual sum of squares.

Assumption is made that the number of population can be an indicator, describing income level of the consumers.

Data was investigated using standard function of linear regression for logarithmic transformation of equation (19):

$$\ln \dot{q} = \ln q_o + \sum_{i=1}^{4} \alpha_i \cdot \ln K_i, \qquad (24)$$

which is widely used in statistical analysis of various economic indicators. Achieved statistical values of investigated parameters are presented in Table 3 and graphical function of heat consumption in Figure 9.

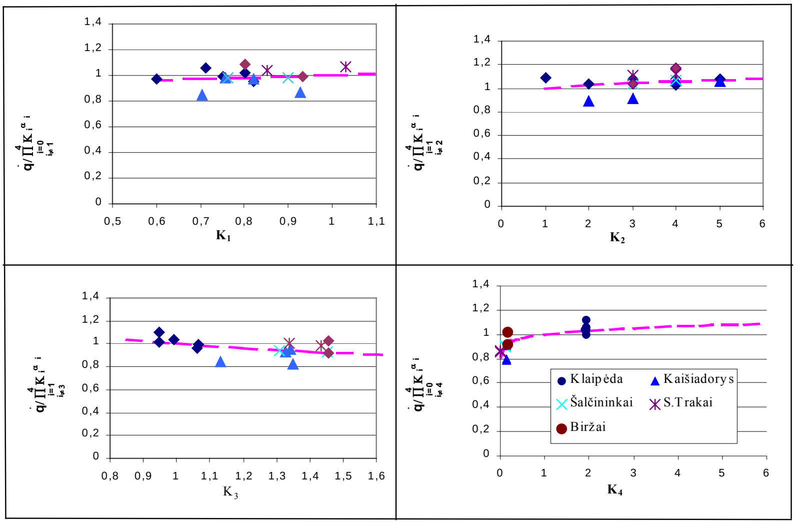

Figure 9. The function of heat consumption vs. investigated external factors

Regardless to the fact that investigated data was for several towns only, achieved statistical value for F is higher than the value of Fisher criterion at 5% reliability level. This permits to evaluate that function (19) with values of indicators, presented in Table 3 dives quite good description of heat consumption vs. investigated external factors and appropriate for assessment and forecasting of the impact of these indicators. We should notify that for achieving mentioned reliability level we had to reject consumption data of Šalčininkai and Senieji Trakai in 2000, which differed significantly from other consumption indicators.

The results of the analysis shows that heat tariff (K_3) and the size of the towns, described by population (K_4) has the highest impact to heat consumption. The latter parameter, though indirectly, reflects the function of heat consumption vs. income level, which is typically lower in small towns. The difference in tariffs ~50% during investigated period reduced heat consumption by appr. 18%. Similar reduction of heat consumption in small towns comparing to Klaipėda, could be defined by lower income level.

Performed analysis also showed insignificant function of heat consumption vs. climate parameter K_1 and the period describing parameter K_2. Insignificant growth of heat consumption during investigated period can show the growth of population income level.

Achieved heat consumption functions for five towns can be used for assessment of heat consumption in other Lithuanian towns, where detailed analysis of heat consumption was not performed.

There is big volume of generalized statistical information on heat consumption in residential sector available in annual accounts of the Lithuanian District Heating Association (LDHA).

Analysis of mentioned data and application of statistical reliability criteria forced to reject data, which differed significantly (more than 30%) from average heat consumption in all towns. This related 10% of data in the mentioned accounts. Heat consumption data in some towns appeared among that rejected data (e.g. Palanga, Visaginas, Elektrėnai), which are rather specific and different from other towns.

The results of data analysis are presented in Figure 10.

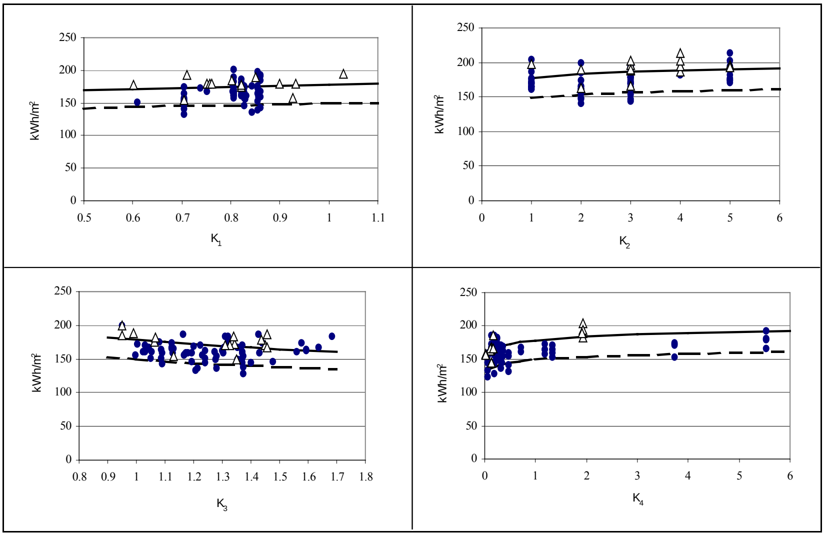

Figure 10. Heat consumption function vs. investigated external indicators: Δ - data of investigated towns, • - data from LDHA

Analysis showed that after assessment of here mentioned deviation, the general trends of heat consumption are similar in all towns as well as more detailed data in investigated small towns. The main difference is that consumption data, provided by the LDHA are some ~12% lower than in above mentioned towns.

One of the reasons for such difference may be inadequacy of heat consumption data in residential sector to official area of heated buildings, however there are also other reasons which can't be identified on the basis of available information.

We can notify that heat consumption in residential sector of Klaipėda city is higher that in other Lithuanian cities. Huge scattering of heat consumption in small towns is still actual for towns with population below 50,000.

This shows that population is not the best indicator for describing solvency and income level.

The function of heat consumption vs. heat tariff is still the important indicator. Investigation of the larger number of towns showed more clear function of heat consumption vs. climate indicators. Over time insignificant growth of heat consumption is still noted. Available data permits to identify the lowest consumption level in 1999 after elimination of the impact of other indicators. Regardless to apparent differences we can state that generalized data on heat consumption can be extrapolated for other Lithuanian towns thus expanding the geography of the results and application. We should suggest the following equation for heat consumption in residential sector:

$$\dot{q} = 170{,}5 \cdot K_1^{0.072} \cdot K_2^{0{,}042} \cdot K_3^{-0{,}2} \cdot K_4^{0{,}045}, \tag{25}$$

which is adequate to the average of all investigated data since 1999 and can be used for forecasting of heat demand.

These results should be considered as finished investigation in defining qualitative functions for heat consumption in residential sector on the basis of the best available accumulated data. The importance of such investigation should be seen as the first step for future research of heat market, showing the importance of creating info system for heat consumption and including larger number of indicators, having impact to this process.

5. THE MAIN CONCLUSIONS AND RECOMMENDATIONS OF THE WORK

Data basis on heat consumption and conditioning indicators (area of the building, number of residents, number of floors in the building), which was accumulated in Klaipėda and some small towns in Lithuania during 1999–2002 period, made assumptions for more detailed qualitative analysis of covering heating demand and permitted to make the following conclusions:

1. It was defined that heat market, that has narrowed during the last decade, is currently stabilizing and the variation of the demand during the last 3–4 years reflects variation of climate conditions, heat savings on the account of comfort level rather than actual reduction of the demand. There is still approximately 30% difference in total heat demand in large and small towns.
2. Trends of heat market, which can be observed from statistical analysis performed in Klaipėda city and some small towns show reduction of buildings with extremely high or low consumption. It is considered to

be the consequence of heat saving and better regulation in the buildings. More general conclusion is that current heat consumption level is close to that, which can be achieved using cheap energy saving measured, which were described in National Energy Efficiency Programme.

3. Weight average of heat consumption in small towns has decreased significantly to the consumption level, which was achieved in Finland after energy crisis of 1970, however such outcome was achieved not through improvement of the efficiency of heat consumption but through reduction of comfort level.

4. Monthly heat consumption data were investigated in 4 small towns for assessment of comfort level and the quality of covering heat demand, which permitted to evaluate average inside balance temperature and ventilation level. Huge variations in inside balance temperatures were notified as well as restrictions on heat consumption for insulation of premises, which are not allowed by valid construction and sanitary-hygienic norms.

   As the results of heat consumption analysis in Klaipėda and 4 small towns show, the value of average balance temperature during investigated period was growing, however this was achieved on the account of reduction of heat consumption for ventilation. Average inside temperature was growing together with comfort level during last four years.

5. Created mathematical model on heat demand in residential sector enables investigation of heat consumption in every residential building included into data basis as well as generalization of achieved results with regard to assess average indicators and changes for investigated group of buildings. Presented theoretical model can be used for forecasting of heat demand with regard to the improvement of buildings envelope till the level, defined by the standards. Heat consumption in small towns is still lower than in large ones and lower comfort level is maintained here.

6. Performed analysis showed that heat tariff is one of the decisive indicators on reduction of heat consumption. Evaluating consumers' solvency and heat tariffs level in small towns we may come to the conclusion that growing of heat tariffs in small tons can't be considered as appropriate measure for solving financial problems of DH companies. Reduction of formed variation in heat tariffs between large and small towns should be the priority guideline for state policy in heat sector.

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Short info about the author:

Jurgita Grigonienė was born on July 17, 1972 in Klaipėda. She started studies on Mechanical Engineering at Klaipėda University in 1990 and gained the Bachelor in Mechanical Engineering in 1994. In 1993 she starts her work in Klaipėda University Mechanical engineering department. J.Grigonienė finished her studies at the University in 1996 where she became the Master of Mechanical Engineering. She entered the post-graduate studies in the direction of Thermal Engineering in 1999. She has finished post-graduate studies in 2005.

REZIUMĖ

Disertacijoje nagrinėjama centralizuotai tiekiamos šilumos namų ūkyje rinka, įvertinant įvairių faktorių įtaką bei išryškinant spręstinas problemas.

Apžvalgoje aptarta centralizuotai tiekiamos šilumos namų ūkiui rinkos tyrimo svarba, išryškinant šalyje egzistuojančią statistinių duomenų, susijusių su šilumos vartojimu namų ūkyje, surinkimo problemą. Apžvelgiama padėtis kitose šalyse. Aptarti kitur taikomi jų sprendimo būdai. Pateikta išsami šalies gyvenamojo fondo apžvalga, klimato įtaka šilumos vartojimui. Pateiktas gyventojų požiūris į centralizuotai tiekiamos šilumos, kaip paslaugos, kokybę. Remiantis atliktų tyrimų apžvalga suformuluoti pagrindiniai disertacijos tikslai ir uždaviniai.

Antroje dalyje pateiktos šilumos vartojimo gyvenamuosiuose pastatuose bazinės lygtys bei statistinės analizės metodų šilumos vartojimui taikymas kiekybinei poreikių patenkinimo analizei, atsižvelgiant į analizuojamų miestų gyvenamųjų pastatų struktūrą.

Trečioje dalyje pateikta išsami šilumos rinkos raidos analizė, panaudojant ketverių metų AB „Klaipėdos energija“ bei kelių rajoninių šilumos tiekimo įmonių šilumos tiekėjų ir vartotojų tarpusavio atsiskaitymo duomenis. Šilumos vartojimo efektyvumo kitimą geriausiai parodo santykinės pastatų šilumos sąnaudos, kurias sąlygoja klimatas, karšto vandens vartojimas, patalpose palaikoma temperatūra bei pastatų šiluminės charakteristikos. Esamas šilumos vartojimas gyvenamuosiuose pastatuose buvo palygintas su projektiniais ir Nacionalinėje energetikos vartojimo efektyvumo didinimo programoje (NEVEDP) pateikiamais bendraisiais šilumos poreikių rodikliais. Esamas žemas vartojimo lygis, mažesnis nei tas, kurį galima būtų pasiekti ekonomiškai pagrįstomis investicijomis į energijos efektyvumo didinimą, galėtų būti vertinamas kaip techninio energijos efektyvumo didinimo potencialo susiaurinimas dėl esamų ekonominių ir socialinių sąlygų. Šilumos poreikių raidos tendencijos, kurias galima stebėti iš metinių šilumos sąnaudų statistinės analizės, rodo pastatų, kurių vartojimas yra ypač didelis arba labai mažas, skaičiaus mažėjimą.

Nepaisant plačios faktinio vartojimo sklaidos, bendrieji šilumos poreikiai turėjo mažėjimo tendenciją. Šilumos galios poreikiai karšto vandens ruošai nedaug tekito. Iš gautų rezultatų galima spręsti, kad šilumos vartojimas mažėja vartotojų komforto sąskaita. Tai leido padaryti išvadą, kad šilumos poreikiai netenkina normalių komforto sąlygų gyvenamuosiuose pastatuose.

Ketvirtoje dalyje aptarta namų ūkio metinių šilumos sąnaudų funkcinių ryšių nuo vidinių ir išorinių veiksnių modeliavimo rezultatai. Matematinio modelio nežinomųjų parametrų nustatymui, panaudota faktinių šilumos vartojimo duomenų ir šilumos poreikių skirtumų minimizavimas.

Siekiant nustatyti temperatūros, laiko, šilumos kainos bei gyventojų pajamų įtaką šilumos vartojimui buvo atlikta šešių miestų sukauptų duomenų šilumos vartojimo daugiaparametrinė analizė. Nesant patikimesnės informacijos buvo padaryta prielaida, kad gyventojų pajamos gali būti charakterizuojamos miesto dydžiu, įvertinant faktą, kad mažų miestų gyventojų pajamos yra mažesnės nei dideliuose miestuose. Analizė parodė, kad didžiausią įtaką turi šilumos kaina bei miesto dydis, apibūdinamas gyventojų skaičiumi. Likusių parametrų įtaka nėra ženkli. Atliktų tyrimų rezultatai buvo palyginti su oficialiai skelbiamais kitų miestų statistiniais duomenims. Pastebėta, kad šių miestų šilumos vartotojų duomenys apie 12% mažesni nei detaliau tirtuose miestuose. Rekomenduota apibendrinta funkcinė priklausomybė šilumos vartojimo namų ūkyje aprašymui. Galima teigti, kad apibendrinta šilumos vartojimo priklausomybė gali būti ekstrapoliuota visiems šalies miestams, šitaip išplečiant tyrimo rezultatų ir išvadų taikymo geografiją.