RIGA TECHNICAL UNIVERSITY
Faculty of Civil Engineering
Institute of Heat, Gas and Water Technology

Aleksandrs ZAJACS
Doctoral Student of Study Programme “Heat, Gas and Water Technology”

ASSESSMENT OF DEVELOPMENT SCENARIOS OF DISTRICT HEATING SYSTEMS

Summary of the Doctoral Thesis

Scientific Supervisor
Dr. sc. ing., Professor
A. Borodiņecs

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DOCTORAL THESIS
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To be granted the scientific degree of Doctor of Engineering Sciences, the present Doctoral Thesis will be publicly defended on 18 January 2017 at 4:00 p.m., at the Faculty of Civil Engineering, Riga Technical University, Kipsalas Str. 6B, Room 250.

OFFICIAL REVIEWERS

Professor, *Dr. habil. sc. ing.* Egils Dzelzītis
Riga Technical Unversity

Senior Researcher, *Dr. sc. ing.* Gaidis Klāvs
Institute of Physical Energetics, Latvia

Professor, *Dr. sc. ing.* Janek Laanearu
Tallin University of Technology, Estonia

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences is my own and does not contain any unacknowledged material from any source. I confirm that this Thesis has not been submitted to any other university for the promotion to any other scientific degree.

Aleksandrs Zajacs …………………………….

Date: ………………………

The Doctoral Thesis has been written in English. It contains the introduction, 4 chapters, conclusions, bibliography with 103 reference sources. The Doctoral Thesis has been illustrated by 51 figures. The volume of the Thesis is 107 pages.

ABSTRACT

The Doctoral Thesis presents a set of qualitative and quantitative studies on trends and problems of the district heating sector development with the aim to quantify possible development scenarios of the DH systems. Optimisation of energy systems has been previously studied by A. Borodiņecs, E. Dzelzītis, G. Klāvs, A. Krēsliņš, M. Aberg, J.E. Christensen, J. Laanearu, H. Lund, etc.

The goal of the Doctoral Thesis is to develop a methodology and planning tool for comprehensive evaluation of district heating system efficiency within different development scenarios.

To achieve this goal, the following tasks have been set:

1) to analyse trends and challenges of the current energy policy of the European Union;
2) to study the future development potential of DH systems;
3) to perform studies on reduction of thermal energy consumption as a result of renovation of DH networks and existing dwellings;
4) to develop the methodology for DH system modelling and evaluation;
5) to develop a dynamic simulation tool for modeling of DH system heat and mass transfer processes and quantitative evaluation of DH system efficiency on the basis of the proposed methodology;
6) to validate the developed tool by comparing the predicted DH system specific parameter values with the measured ones;
7) to simulate the proposed DH system development scenarios and select the most advantageous ones based on evaluation criteria values.

Scientific Novelty. The model with multiple integrated heat and mass transfer processes has been developed on the basis of the proposed methodology for the modeling and assessment of the 4th generation DH systems under changing thermal energy consumption.

Practical Application. The developed methodology and district heating planning tool are practically applicable by planning and development departments of heat supply system operators and municipalities for evaluation and increase of the efficiency of DH systems.

The Doctoral Thesis has been written in English. It contains the introduction, 4 chapters, conclusions, bibliography with 103 reference sources. The Doctoral Thesis has been illustrated by 51 figures. The volume of the Thesis is 108 pages. The results of the Doctoral Thesis have been reported in 10 international conferences and published in 11 scientific publications.

CONTENTS

INTRODUCTION

In recent years, people have become aware that urban environment is a comprehensive resource that requires smart management. This has led to the increased need for introduction of decarbonization policies, use of sustainable resources and development of sustainable cities with integrated smart disciplines – economics, energy sector, technologies, architecture and politics. Special attention should also be paid to city resilience planning due to its importance for any city development as well as the national securitisation process by becoming better prepared and more responsible for national risk management, including independence of imported energy sources. By "city resilience", one typically understands sustainable energy management, securing stable energy supply, reducing energy consumption, and developing renewable energy sources.

According to Article 9 of Directive 2010/31/ES of the European Parliament, Member States shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings. Under the Kyoto Protocol, by 2020 the European Union must reduce emissions by 20 %, but since December 2015 the EU is committed to new ambitious goals of global climate change agreement – Paris Protocol. Ambitious national greenhouse gas reduction targets include 40 % cut by 2030 compared to 1990 levels and specifying that the long-term goal should be to reduce global emissions by at least 60 % below 2010 levels by 2050. The goals also include reaching 27 % share of renewable energy consumption, 27 % energy savings compared with the business-as-usual scenario and limiting a dangerous rise in global average temperature to below 2°C compared with pre-industrial levels by 2030.

Achieving significant energy savings is only possible if there is a clear identification of priority sectors as well as mobilisation of investment capital that can be easily accessed. The building sector is responsible for about 40 % of energy consumption in the European Union; therefore, reducing the energy use in buildings and improvements in district heating (DH) and cooling sectors are top priorities to achieve reduction in fossil fuel consumption and CO_2 emissions. Natural gas consumption could be cut by one-third if the renovation of buildings is speeded up. In the Northern Europe climate, it is found that human behaviour can lead to 50 % higher heating demand and 60 % higher heating power than those anticipated in the reference values in the standard calculations for energy demand patterns in energy-efficient buildings.

In order to properly respond to future changes in energy demand and implement advantageous development of district heating sector, it is necessary to have a tool for evaluation of the planned DH system development scenarios based on a set of actual qualitative and quantitative studies on the district heating sector development trends and problems.

1. POLICY REVIEW AND ENERGY BALANCE

1.1. Energy Policy of the European Union

The European Union has legislated in the area of energy policy for many years, the concept of introducing a mandatory and comprehensive European energy policy was approved on 27 October 2005. The EU Treaty of Lisbon of 2007 legally includes solidarity in matters of energy supply and changes to the energy policy within the EU.

In January 2014, the EU agreed to a 40 % emissions reduction by 2030, compared to 1990 levels, and a 27 % renewable energy target. The target is the most ambitious of any region in the world, and is expected to provide 70,000 full-time jobs and cut €33 bn in fossil fuel import. The Swedish national energy efficiency goals aim to reduce total energy use by 20 % until 2020 as compared to the levels in 2008. There are also goals for Swedish buildings; the specific energy use per heated area is to be reduced by 20 % until 2020 and 50 % until 2050, below the levels in 1995. Germany is contributing significantly to achieving ambitious national targets of the EU's efficiency targets, i.e. reducing primary energy consumption from 2008 levels by 20 % by 2020 and by 50 % by 2050. The Climate Change Act 2008 established legally binding targets for reduction of CO_2 emission in the UK by at least 34 % by 2020 and 80 % by 2050 against the 1990 baseline.

1.2. State of the Art of District Heating System in Latvia

Over the past decades Latvia has been undergoing the modernization process of heating plants. There were a lot of obsolete heating plants with high capacity, which were designed for bigger number of inhabitants and higher heat energy consumption. In the early 1990s, energy policy changed from "unlimited" energy consumption to the "efficient" energy consumption. This process was aimed at optimising the heat energy production – distribution – consumption cycle in order to reduce energy bills for end users.

Analysing the statistical data of the Latvian Central Statistic Bureau, it was defined that the total installed heat capacity of all heating plants in Latvia reduced along with the total number of heating plants (see Fig. 1.1).

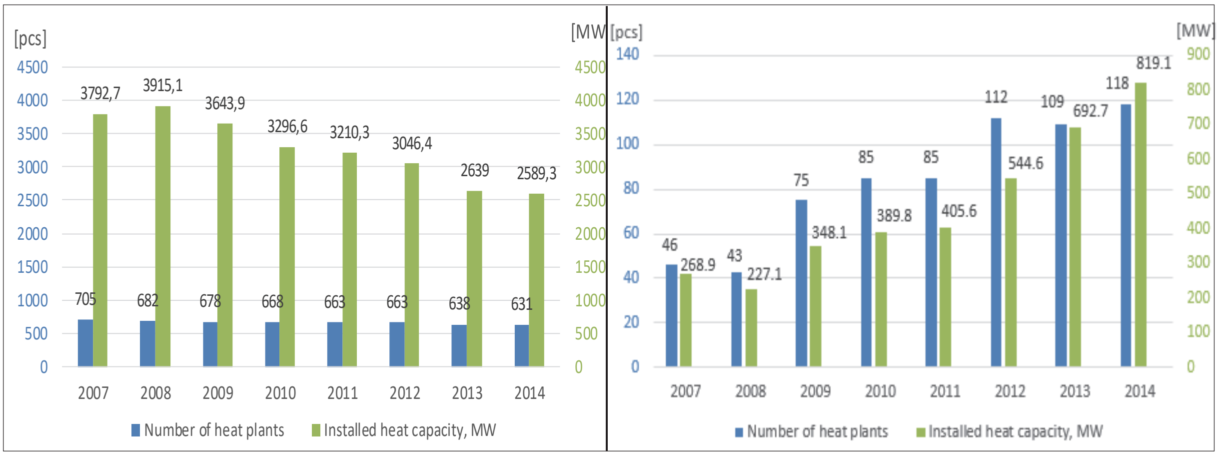

Fig. 1.1. Number and installed capacity of DH plants (left) and heating plants using wooden chips (right) in Latvia during the period from 2007 to 2014.

Of the total number of heating plants in 2014, 86 % or 544 heating plants were with capacity <= 5 MW and the rest 14 % or 87 with capacity greater than 5 MW, including 7 heating plants with capacity >50 MW. Only in the last 7 years, 74 heating plants were decommissioned.

The analysis of the biomass use in Latvia showed that the usage of renewable biomass energy sources was actively developed and during the same seven-year period the total number of coal stations reduced from 22 to 3, and the number of burning natural gas heating plants decreased from 296 to 267. However, the number of heating plants running on renewable wooden chips increased by 2.5 times and the installed capacity in 2014 became three times higher than it was in 2007. Statistics shows that in the period from 1990 to 2014 energy dependency of the EU (all Member States) increased from 44.2 % to 53.4 %. This emphasises the importance of reducing energy imports and using local renewables.

2. METHODOLOGY

2.1. Basic Methods and Principles

The balance of district heating system is determined by equilibrium of produced and consumed thermal energy amount. District heating operators have an option to predict precisely heat demand depending on outdoor temperature using statistical data. Thermal energy distribution and consumption efficiency is directly related to the historical – architectural differences of the city/district, and in different locations it will be a floating number. Any changes in the system parameters will affect system efficiency, which can be tracked by district heating system efficiency indicators (see Fig. 2.1). Use of efficiency criteria will also assist in the assessment of DH system development scenario and achievement of better efficiency of the DH system.

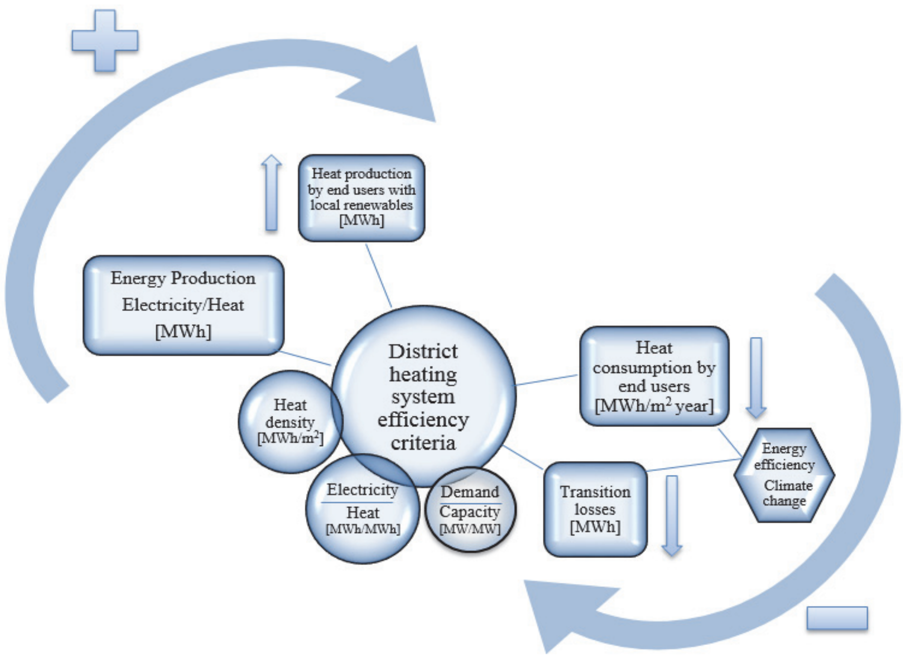

Fig. 2.1. District heating system balance and efficiency indicators.

Methodology is based on a set of qualitative and quantitative studies, which provide insight into the district heating (DH) sector development trends and problems. The 1st and 2nd chapters present qualitative studies, which review trends in actual energy policy of the European Union, potential development of DH systems and actions in smart cities. Studies have shown that in general there are two time periods under review until year 2020 and 2050, when the EU member states have stated their own targets on reduction of energy use from 20 % to 80 %, respectively.

Thus, considerable actions in increase of building energy efficiency are predicted, which will strongly affect DH system performance and possible development scenarios.

Results of quantitative studies performed within the 3rd chapter of the Doctoral Thesis evidently represent the achievable level of reduction of thermal energy consumption in the existing DH systems, particularly focusing on reduction of heat losses in the distribution network, as a result of DH network renovation, and in energy consumption by end users, as a result of ongoing rising of energy efficiency of existing dwellings.

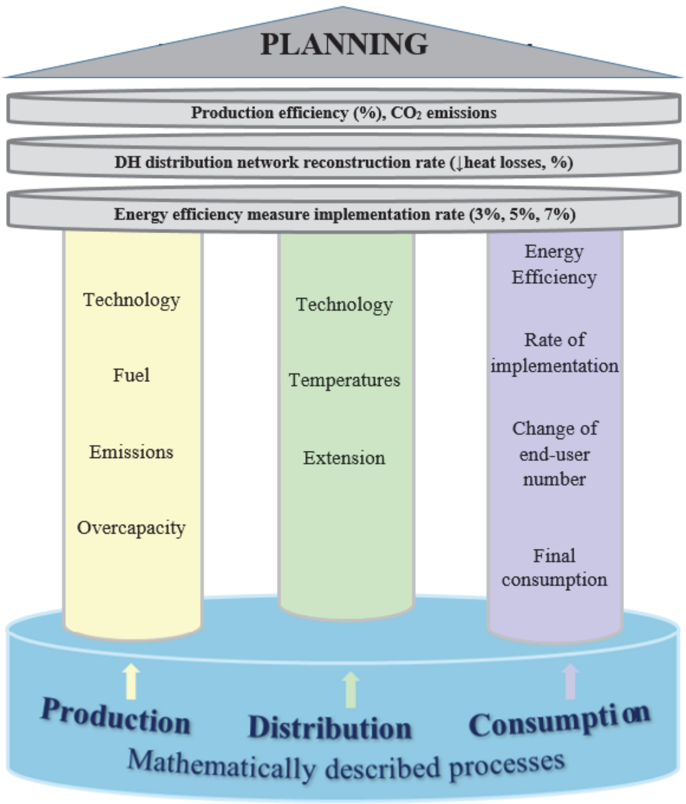

Fig. 2.2. Scheme of the developed methodology of smart district heating planning tool.

Data for quantitative research were collected remotely from heat meters located in individual heating units' room and heating plant. Data were statisticaly evaluated and standard errors (SE) for each building were calculated. For unrenovated buildings the SE was between 1.2–2.5 with average ±1.8 kWh/m^2 per month or ± 6.3%, and for all considered buildings the SE was between 1.2–4.2 with average ±2.1 kWh/m^2 per month or ±7.2%.

Planning tool is based on a dynamic simulation model of integrated system multiple heat and mass transfer processes in the whole DH system as shown in Fig. 2.2. Vertical pillars represent the main changing parameters of thermal energy production, distribution and consumption processes within one DH system. Each horizontal disc represents changing parameters within one scenario. Theoretically the number of discs is unlimited, but within this

Doctoral Thesis three changing parameters have been considered in each scenario and additionally the option to change thermal energy production source types and capacities has been examined.

The planning tool is considered to be limited within one district heating system, but theoreticly it has no limits and could be moved to the city scale or combine several district heating systems by further development.

2.2. Study on Heat Distribution: Optimisation of Heat Losses

In general, the heat carrier temperature drop in a short section of DH pipeline is directly proportional to the length of the pipe and its diameter and inversely proportional to the flow rate of heat carrier. Usual calculations are valid for the case when heat transfer coefficients and the heat carrier temperatures are constant along the length of the pipeline. It corresponds to the situation when pipelines have a good insulation layer, but since calculations have been made for obsolete pipelines before the replacement, reduction of the heat carrier temperature occurs due to the poor insulation quality, and the average temperature of the heat carrier is different from the initial one. Due to the unevenness of the surface temperature of the pipeline, coefficient values of the convective and radiant heat transfer from the surface of the pipe are not constant.

For more reliable results, the following calculation method of heat losses is proposed, taking into account exponential nature of heat transfer reduction by the specified relationships. For this purpose, it is necessary to use a mass flow rate of the heat carrier G_w.

Relationships can be derived from the differential equation describing the process of heat transfer from the surface of the pipeline section length and the differential equation describing the heat flow as a result of the heat carrier cooling:

$$\begin{cases} dQ = h_{op}\,(T_p - T_{out})\,\pi\, D_{op} \cdot dL \\ dQ = c_w\, G_w\, dT_w \end{cases}, \tag{2.1}$$

where

dQ – heat losses of the pipeline section, kJ/h; dL – infinitesimal length of the pipeline; dT_w – decrease of the heat carrier temperature at infinitesimal unit of length, K; c_w – specific heat capacity of water, kJ/(kg K); h_{op} – heat transfer coefficient of the process, kJ/(m^{2}h K); T_{out} – outdoor air temperature, °C; T_p – temperature of the pipeline surface, °C; D_{op} – outer diameter of pipe, m; G_w – mass flow rate of the heat carrier, kg/h.

Within the framework of the Doctoral Thesis, research on optimisation of heat losses was performed for one district heating system consisting of one heating source and 23 multi-apartment buildings. The total length of district heating network was 1890 m, of which 1043 m of pipelines were installed underground (old concrete shell) and the rest 847 m – through the basement of the buildings.

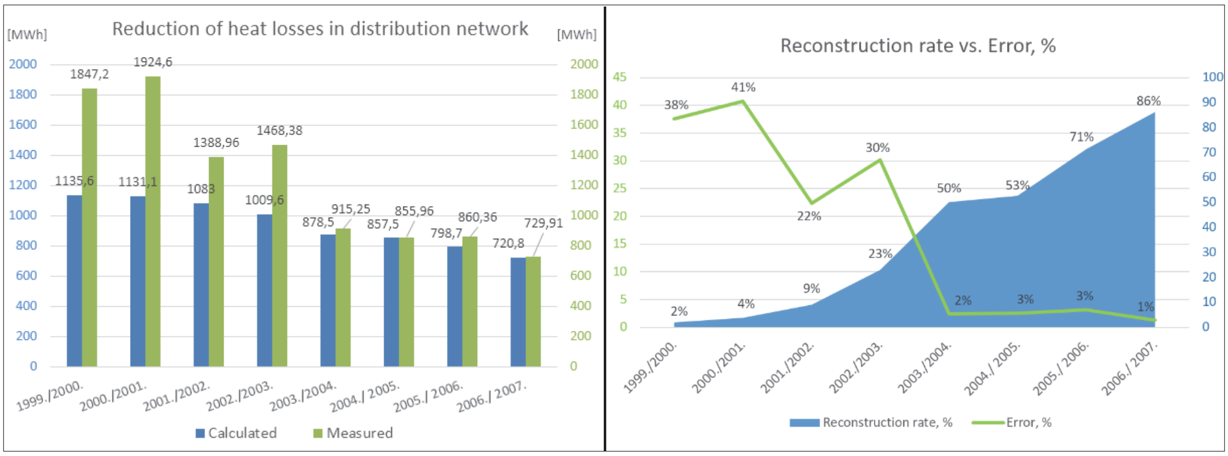

Fig. 2.3. Calculated and factual reduction of heat losses in the distribution network (left) and the share of renovated DH distribution network pipelines vs. deviation between the calculated and measured values (right).

In the period from 1999 to 2007, the calculated reduction of the heat loss was 37 % and real reduction of the heat losses was 60.5 % in same heating period. Results of the actual and calculated reduction of heat losses in the heat distribution network were obtained and outlined in Fig. 2.3 (left). At first sight, the calculation method seems too inaccurate, but from year 2002/2003 to 2006/2007, when 85 % of pipelines laid underground were replaced, deviation between the calculated and measured values did not exceed 1 % as outlined in Fig. 2.3 (right). Year 1999 was the beginning of preinsulated pipe system introduction, and the transition process was limited both financially and technologically. It can be explained by the fact that the initial state of the pieplines was much worse than expected. Reconstruction process was uneven and during 4 years only 23 % of the distribution network was reconstructed. Lack of funds and experienced workers forced to select sections for the reconstruction very carefully – only the ones where the heat network was in a dangerous condition and threatened the security of heat supply. When the share of renovated pipelines reached 50 % in the year 2003/2004, the calculation accuracy increased significantly and differences between the actual measured data and calculation results did not exceed 3 %.

2.3. Research on Energy Efficiency of Residential Buildings

The statistical data of CSB shows that in 2011 in Riga the heated area in the residential sector, receiving heat from external sources, was **12.6 million m^2**. REA information shows that the average actual specific consumption of thermal energy of complex renovated apartment blocks in 2014 (actual average outside air temperature of heating season 2014/2015 was +2.5 °C) in Riga buildings with the centralised hot water supply was 107 kWh/m^2/per year, but in buildings without centralised hot water supply – 69 kWh/m^2/per year. In 2014, the average specific heat consumption of residential buildings in Riga was:

– in buildings with centralised hot water supply – 177 kWh/m^2/per year,

– in buildings without centralised hot water supply – 136 kWh/m^2/per year.

According to the data of the Ministry of Economics of the Republic of Latvia, till 2015 the total number of already renovated multi-storey buildings in Latvia had reached 635 buildings. These numbers show the high interest in the refurbishment process, which is stimulated by the possibility to attract EU funds.

In order to estimate possible reduction of heat energy consumption in multi-apartment buildings, the research of the renovation results was performed within the framework of the Doctoral Thesis. Information about 55 multi-apartment buildings was collected: total area, total heated area, type (series), year of building, year of renovation, domestic hot water preparation (centralised or individual), hot water circulation (yes/no). Monthly heat energy consumption data were collected for a 5-year period – 2010-2014. The investigated buildings have different inner heating systems (one-pipe, two-pipe, with top distribution and with bottom distribution) and also some of the buildings do not have centralised domestic hot water preparation. Buildings are divided into 5 groups depending on the renovation year in order to evidently visualise the reduction in consumption after renovation.

Later on data were corrected by degree-days in order to bring them to similar weather conditions in respect of outside air temperature and duration of the heating season. Out of the 55 multi-apartment buildings marked on the map as renovated only 31 were really finished at the moment of research. Out of them only 5 buildings were renovated in the year 2013/2014, so it was not possible to spot any changes in energy consumption at the moment of the research. Results of the other 26 buildings are presented in Fig. 2.4.

Comprehensive renovation of buildings resulted in heat consumption reduction by approximately 40 % from 130–140 to 75–80 kWh/m^2. Differences in the reduction of heat energy consumption are explained by the fact that different energy efficiency measures were implemented in different buildings. Unfortunately, none of the analysed buildings underwent reconstruction or employed a new mechanical ventilation system that jeopardised IAQ in the living space. Other local studies showed that in buildings without ventilation CO_2 concentration exceeded a maximal value of sensors – 2500 ppm, and installation of new airtight windows and thermal insulation leaded to unsatisfactory indoor air quality.

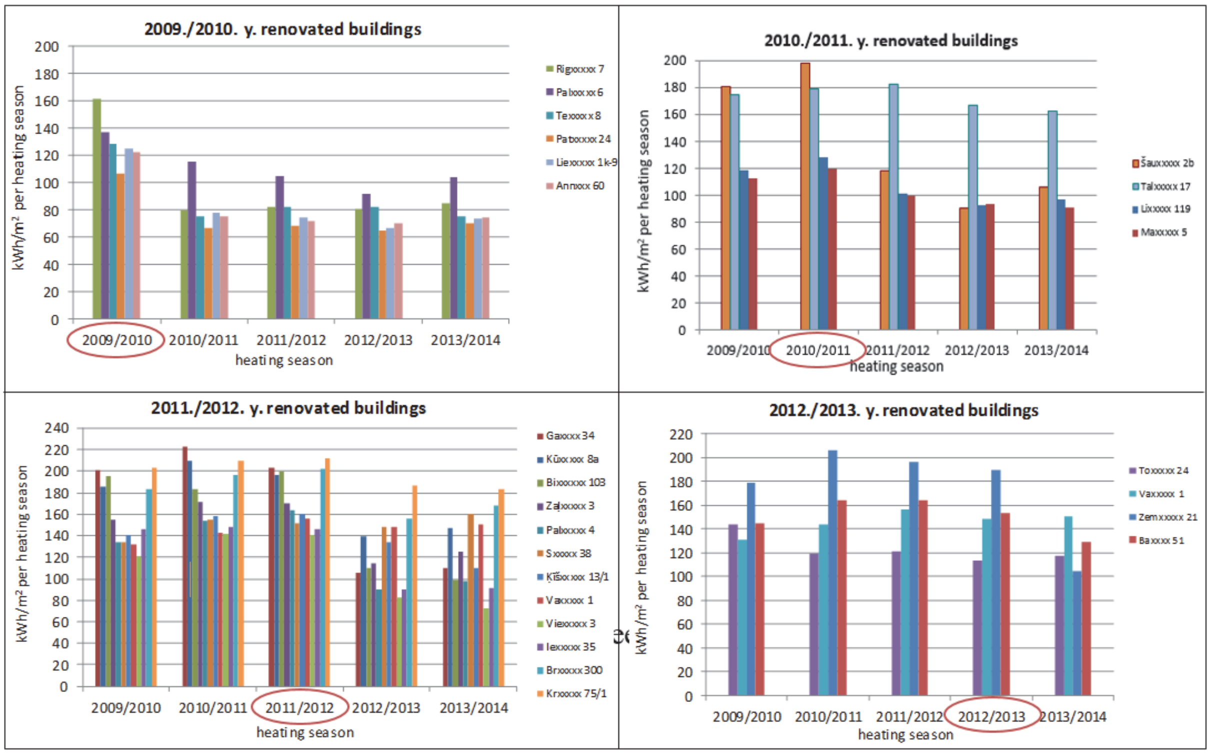

Fig. 2.4. Heat energy consumption of multi-apartment buildings
before and after renovation in the city of Riga.

The studied buildings were insulated according to the previous normative requirements, which were valid until April 2014. Since April 2014, Latvia has significantly reduced normative heat transfer values, as it is shown in Fig. 2.5.

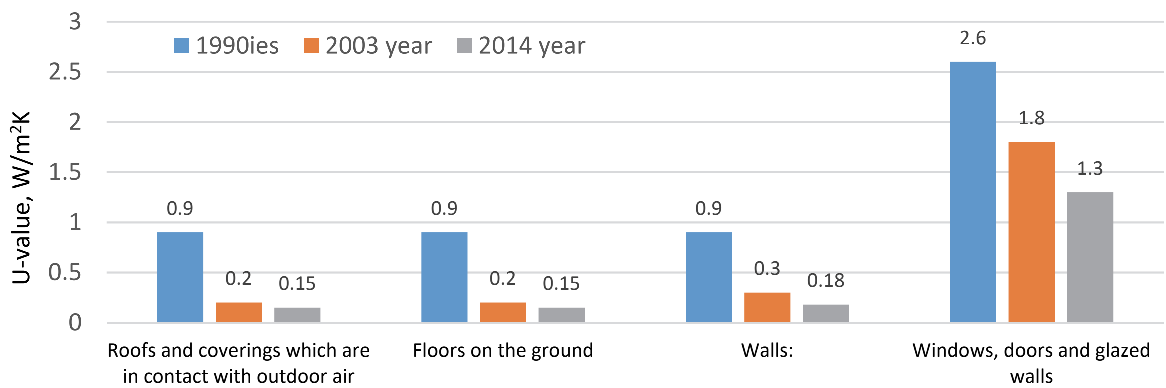

Fig. 2.5. Comparison of normative U-values in Latvia since the 1990s.

Additionally, to consider the situation from a different perspective (thermal energy production), the study on heat load reduction of 8 DH plants in Riga during the past decade was performed. When converting the heat loads of different heating seasons at the same temperature of - 20.7 °C, the calculated results showed that the biggest heat source HPs "IAT" had no significant heat load change during last 10 years. It can be explained by the fact that the reduction of heat losses in the heating network and energy efficiency measures in the buildings are compensated with load growth due to connecting of new heat consumers.

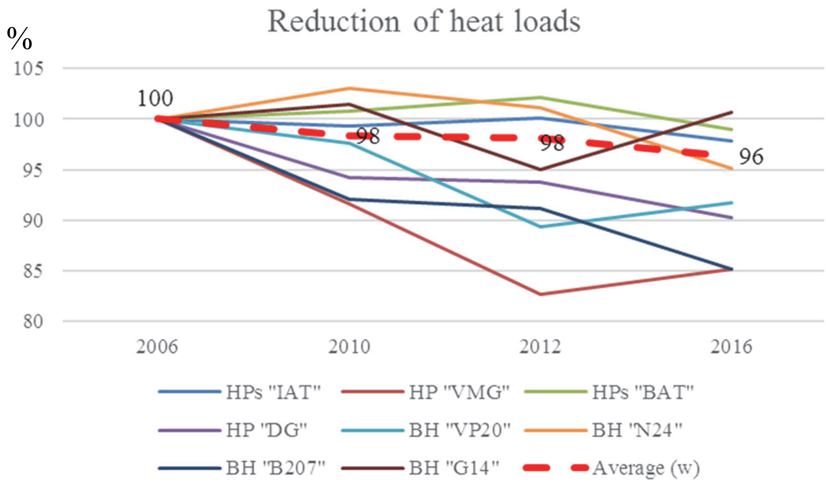

Fig. 2.6. Heat load reduction for different heat sources.

The largest reduction, compared to 2006, is for HP "VMG" approximately by 15 %, BH "B207" by 15 %, HP "DG" by 10 %, BH "VP20" by 8 % with the installed capacity of 63 MW, 6 MW, 32M W and 7 MW respectively. Such a big decline can be explained by the fact that apart from the increasing energy efficiency of the district heating system, socio-economic factors motivate inhabitants to look for a more attractive place to live.

At the same time, the weighted average heat load for all 8 heating sources reduced by 4 % comparing with 2006, and one of the reasons was reduction of population in Riga, which has been declined by 3.3 % over the last decade, according to the data of Riga City Council.

3. SMART DISTRICT HEATING SYSTEM PLANNING TOOL

3.1. Development of the Smart District Heating Planning Tool

The developed algorithm of the planning tool will include several stages, such as *evaluation, calculation, linking, validation, scenario integration, and interpretation.* Evaluation is carried out in order to understand what input data is needed and what results or criteria have to be included in the final output block. The planning tool consists of nine separate blocks and each block calculates each process based on heat and mass transfer laws, and correlations are linked together in order to tie up all processes in the common system and make them dependent on each other. For this purpose, any spreadsheet software is considered to be appropriate software.

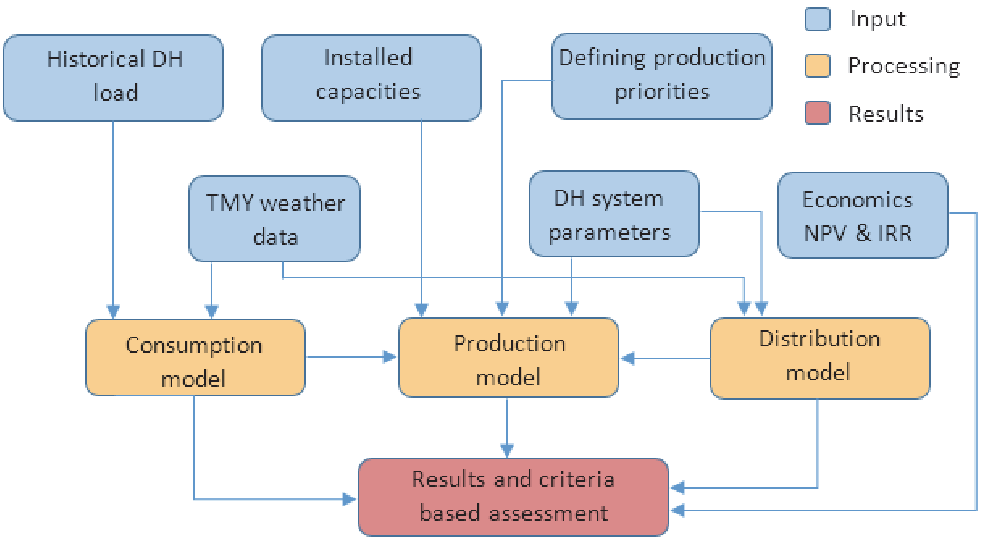

Fig. 3.1. Workflow of the planning tool.

Consumption model is described mathematically by Fourier's law of heat conduction for steady state (no heat generation in the element Qin = Qout) one-dimensional (temperature depending on one variable only) heat conduction (equation 4.2 in the Doctoral Thesis) and Newton's cooling law in convection (equation 4.3 in the Doctoral Thesis). Since transmission heat losses through the building envelope depend on conduction and convection heat transfer, the transmission heat losses can be rewritten as follows:

$$\dot{Q}_t = \frac{(T_\mathrm{i} - T_\mathrm{o})}{\frac{1}{h_1 A} + \frac{L}{Ak} + \frac{1}{h_2 A}} \quad , \tag{3.1}$$

where

Q_t – transmission heat losses through the envelope element, W; k – thermal conductivity of the building envelope element, W/(m °C); h – heat transfer coefficient (1 – inside, 2 – outside), W/(m^2 °C); L – thickness of the envelope element; A – area of the envelope element, m^2; T_i – inside temperature, °C; T_0 – outside temperature, °C.

In order to describe heat consumption for ventilation and hot water consumption, which are the main components of building energy balance, since hot water consumption continues throughout the year, the following equation is used with respect to the heat transfer media:

$$\int_{t=0}^{\tau} \dot{\mathrm{Q}}_\mathrm{m}\,\mathrm{d}t = -\int_{T=T_0}^{T_s} \rho_m V_\mathrm{m} c_m\,\mathrm{d}T, \tag{3.2}$$

where

Q_m – heat load for ventilation, infiltration or hot water preparation, kJ/h; ρ_m – heat transfer media density, kg/m^3; c_m – specific heat capacity of heat transfer media, kJ/(kg°C); V_m – flow rate of heat transfer media, m^3/h; T_s – supply temperature, °C; T_o – outdoor or cold water temperature, °C; t – time, h.

For precise calculations, the consumption model has to include yearly outdoor temperatures. Climatic data for the developed model are adjusted for Riga by inputting the detailed hourly temperatures of typical meteorological year (TMY). For any other locations, average monthly temperatures can be approximated using trigonometric functions and hourly temperature data can be calculated using this equation:

$$\theta = \theta_{avg} + \theta_{amp} \cos\left(\frac{2\pi t}{365.25} - (-\phi_{fs})\right), \tag{3.3}$$

where

t – time in days (for hourly simulations 1 hour = 0.0416 days); θ_{avg} – average annual temperature (for Riga 7.38), °C; θ_{amp} – annual amplitude (for Riga 11.15), °C; ϕ_{fs} – related phase shift (for Riga 2.858), rad; 365.25 – a period of 1 year corrected for the leap years, days.

Results of Fourier analysis give constants of amplitude and a phase shift for the city of Riga. The measured temperatures can be compared graphically versus results of Fourier approximation with 1 harmonic in Fig. 3.2.

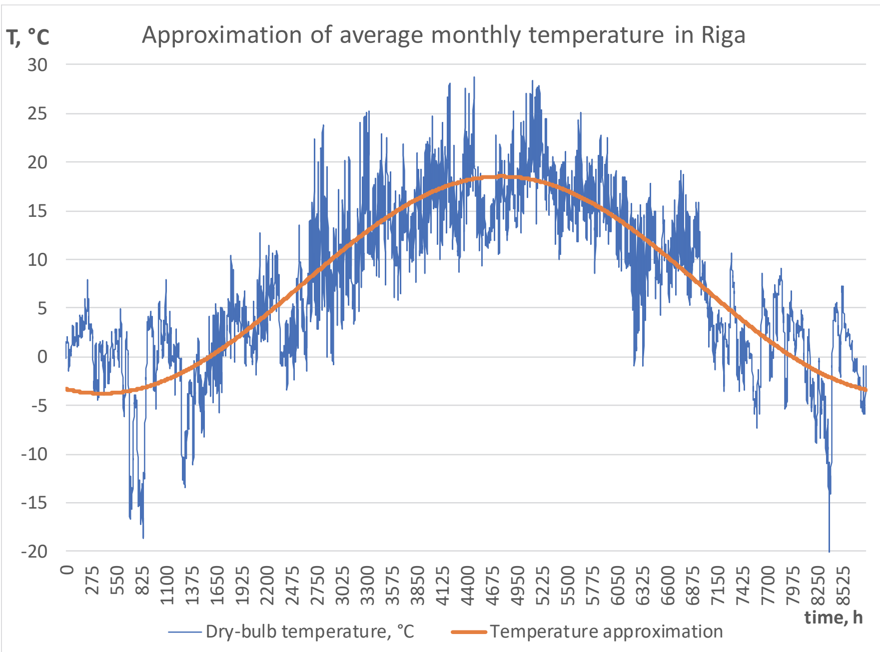

Fig. 3.2. Approximation of hourly outdoor temperatures in Riga.

Economic section is not linked with other spreadsheets because it does not influence technological assessment. Economic section can be used for the calculation of net present value (NPV) and internal rate of return (IRR) of individual development measures. The purpose of economic evaluation is to identify the best course of action based on available evidence.

Working parameters of the whole system are described mathematically and predicted with certain probability. The consumption model (heat energy demand and consumption by end users) of every system will have its own features and characteristics since behavior of inhabitants will vary from place to place.

3.2. Validation of the Smart District Heating Planning Tool

For the simulation of development scenarios, a real district heating system was considered. There are the following main characteristics of the system for a basic overview:

Installed heat capacity – 6 MW (2x3 MW natural gas fired boilers);

Cogeneration unit capacity – 600 kW_{th};

Residential sector – 51069 m^2 of heated area;

Distribution network – 1962 m (outside 1138 m, basement – 824 m);

Flow/return average temperatures – 75/55 °C.

Validation was made for two system states (previous state and actual state), since all the system historical data were available. In summary, the results of actual state of the system scenario are presented (Fig. 3.3). Actual state of the system has the following conditions: distribution network is renovated by 85 %, co-generation unit is installed, residential sector energy efficiency – without changes.

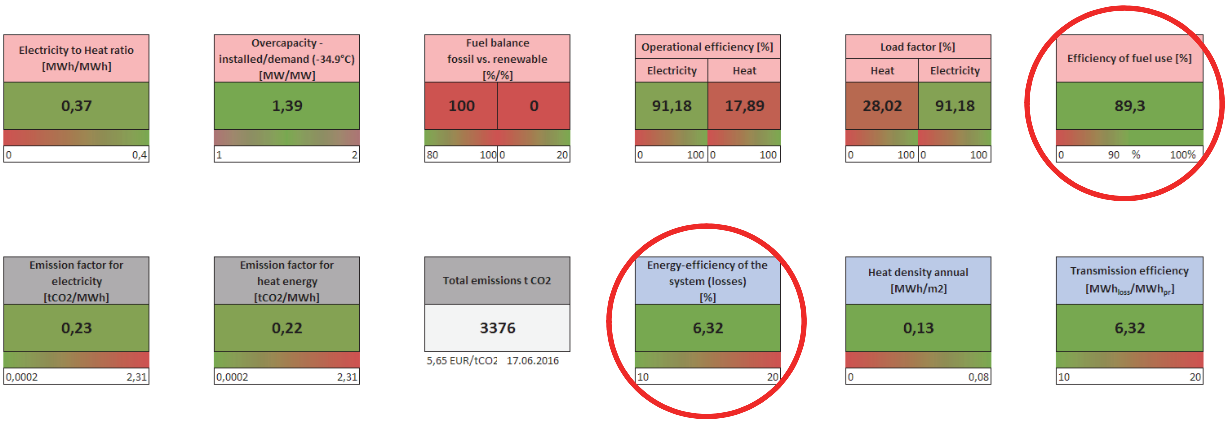

Fig. 3.3. Actual state of the system evaluation results.

To determine the deviation between theoretically predicted and measured values, the mean absolute percentage error was calculated. At all validation stages, accuracy of the calculated results was within 8 %. Accuracy strongly depends on the actual environmental conditions, system state (new or obsolete equipment) and other uncertain parameters, such as human energy consumption habits.

3.3. Different Scenario Simulations with the Smart District Heating Planning Tool

In the framework of the Doctoral Thesis, 6 different district heating system development scenarios with the following changing conditions were proposed, assessed and simulated:

a) *Reference scenario* – old distribution pipelines, production of heat only in natural gas fired heating boiler, residential sector is not renovated;

b) *Actual state* – distribution network is renovated by 85 %, co-generation unit is installed, residential sector energy efficiency is without changes;

c) *Realistic renovation* – residential sector renovation rate 3 % of the buildings every year, 100 % renovation of distribution network, co-generation unit is installed (15-year perspective);

d) *Intense renovation* – residential sector renovation rate 5 % of the buildings every year, 100 % renovation of distribution network, co-generation unit is installed, wooden biomass fired water boiler 2MW installed (15-year perspective);

e) *Enhanced renovation* – residential sector renovation rate 7 % of the buildings every year, 100 % renovation of distribution network, co-generation unit is installed, local solar collectors installed, temperature graph in distribution network 55/35 °C (15-year perspective);

f) *Realistic renovation and biomass use* – residential sector renovation rate 3 % of the buildings every year, 100 % renovation of distribution network, co-generation unit is installed, wooden biomass fired water boiler 3MW installed, flow/return temperatures in distribution network 55/35 °C (15-year perspective).

Priority for thermal energy production was set for most efficient and feasible technological units such as co-generation units, biomass fired boilers and other units that use renewable energy sources to cover base load, after which other production units will be used to cover peak demand.

Installed Heat capacity	6,97	MW
Capacity of installed cogeneration unit	0,5	MW el
	0,637	MW th
Peak load for heating period (heat)	3,84925	MW
Peak load for heating period (electr)	0,5	MW

Total Emissions	2990,447	tCO2
Emissions for heat	2112,16	tCO2
Emissions for electr	878,29	tCO2

Production programs

Cogeneration heating plants

	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hours year		744	672	744	720	744	720	744	744	720	744	720	744	
Working hours of cogeneration unit	h	744	672	744	720	744	720	744	744	720	744	720	744	8 760
Working hours of natural gas boilers	h	744	672	744	720	0	0	0	0	0	744	720	744	5 088
Heat energy to the network	**MWh**	**1443**	**1284**	**1237**	**874**	**339**	**307**	**311**	**313**	**307**	**623**	**1017**	**1335**	**9 392**
Average heating load	MW	1,94	1,91	1,66	1,21	0,46	0,43	0,42	0,42	0,43	0,84	1,41	1,79	
Cogeneration unit el.load	MW	0,50	0,50	0,50	0,50	0,36	0,33	0,33	0,33	0,33	0,50	0,50	0,50	
alfa (electr/heat)		0,785	0,785	0,785	0,785	0,785	0,785	0,785	0,785	0,785	0,785	0,785	0,785	
Cogeneration unit produced electr.	MWh	372	336	372	360	266	241	245	246	241	372	360	372	3 783
El. self-consumption of cog.unit	MWh	46	46	50	27	15	14	15	13	14	17	47	39	343
Electricity to the grid	MWh	326	290	322	333	251	227	230	233	227	355	313	333	3 440
Heat load of cogeneration unit	MW	0,64	0,64	0,64	0,64	0,46	0,43	0,42	0,42	0,43	0,64	0,64	0,64	
Heat energy produced by cogeneration unit	**MWh**	**474**	**428**	**474**	**459**	**339**	**307**	**311**	**313**	**307**	**474**	**459**	**474**	**4 819**
Heat energy poduced by heating boiler (ng)	**MWh**	**969**	**856**	**764**	**416**	**0**	**0**	**0**	**0**	**0**	**149**	**558**	**861**	**4 573**
Natural gas consumption	th.m3	219	196	195	151	76	69	70	70	69	123	168	207	1 611
Efficiency water boiler		0,93	0,93	0,93	0,93	0,93	0,93	0,93	0,93	0,93	0,93	0,93	0,93	
Efficiency cogeneration unit		0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	
Total efficiency		0,90	0,90	0,90	0,89	0,87	0,87	0,87	0,87	0,87	0,88	0,89	0,90	0,89
Heat energy produced by renewables	MWh													0

Fig. 3.4. Production program for "realistic renovation" scenario.

Production amount was set by working hours and load of the corresponding equipment shown in Fig. 3.4. Use of diversificated energy sources improves the reliability of the system operation. Natural gas fired boilers are considered the best technology to cover peak demand, since they are fully automated, have short start time and easy regulation.

Realistic Renovation and Biomass Use Scenario

The last simulated development scenario is considered to overcome all the previously detected shortcomings and to provide maximum benefits for district heating operator and end-user simultaneously. This scenario is the most attractive one from the technological point of view since the load factor for cogeneration unit is high comparing with data in literature, which usually takes the values of 50–60 %. Load factor and operational efficiency for heat production are not so good since water boilers are operated only in periods when a cogeneration unit cannot provide all required heat load, and this occurs rarely and only during the heating period. However, the reduction of installed capacities is not an option if DH operator is willing to comply with safety requirements for district heating supply systems.

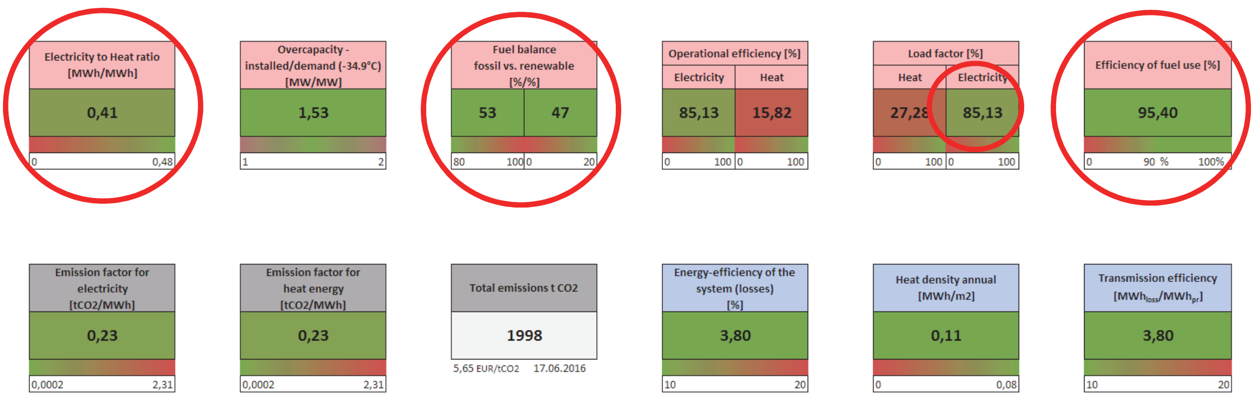

Fig. 3.5. Evaluation results of "realistic renovation and biomass use" scenario.

Renovation of residential sector has influenced total heat demand and comparing with non-renovated building stock (10 231 MWh_{th} annualy) the realistic renovation development scenario in a 15-year perspective would reduce total heat demand to 8 850 MWh.

Heat losses in the distribution network that are represented by transmission efficiency are relatively low – only 3.8 %. It shows that by reducing flow and return temperatures of the water in the distribution system it is possible to reduce heat losses more than by 35.6 % or 193 MWh, in money terms it is 7 851 Euro annually, comparing with a realistic renovation scenario. It could be more beneficial for larger systems and urban regions.

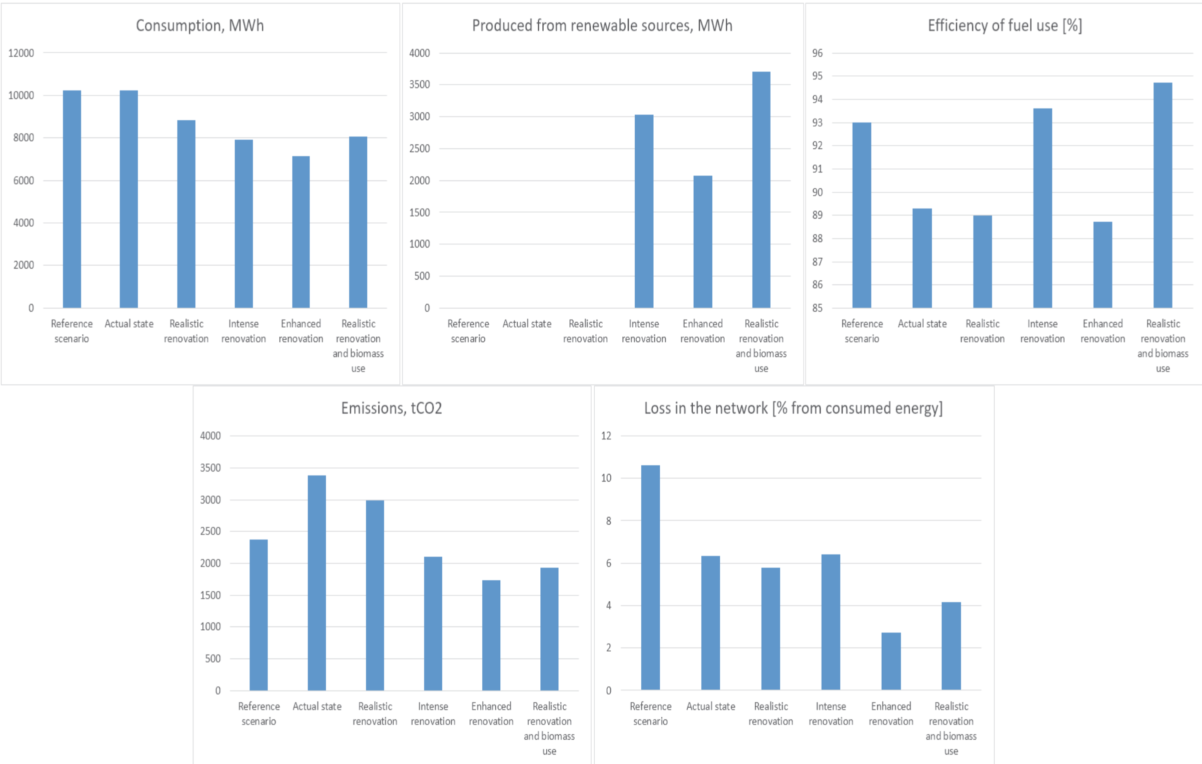

Fig. 3.6. Comparison of six development scenarios of DH system (output from the smart district heating planning tool).

Share of renewable sources has reached 47 % in the last development scenario reducing total emissions, but natural gas fired water boiler is used only about 260 hours per year to cover peak load, which occurs only when outdoor air temperature is below −22 °C. Recovering latent heat by water vapour condensation in the flue gases from wooden biomass fired water boiler, there is an increase in overall efficiency of fuel use up to 95.4 % by a lower calorific value. Results of other 6 scenarios are presented in Fig. 3.6 and the detailed description of their qualities is provided in the full text of the Doctoral Thesis.

CONCLUSIONS

1) There are two time periods under review until year 2020 and 2050, when the EU member States have stated their plans on reduction of energy use from 20 % to 80 %, respectively.
2) During the time period from 2007 to 2014, a number of heating plants running on wood chips in Latvia increased by 2.5 times and the installed capacity reached 819 MW (3 times higher), comparing to 2007 with 65 % share of citizens served by district heating.
3) Comprehensive research of 55 renovated buildings in Riga in the period from 2010 to 2014 has shown a decrease in thermal energy consumption from 35 % to 50 % (average 42.3 %) as a result of complex renovation of existing multi-apartment buildings.
4) Study of optimisation of heat losses in the DH distribution network shows strong correlation between the calculated and measured values (deviation does not exceed 2 %) for new preinsulated pipes, but much lower precision when estimating heat losses from obsolete heatig pipelines, where deviation reaches 41 % (maximum)of the measured values. It can be explained by the fact that the old pipeline insulation material was much worse than it was considered, and it was not possible to inspect pipeline condition and adjust a calculation method.
5) Results of the performed qualitative and quantitative studies have served as a basis for the development of methodology for DH system modelling under the changing thermal energy consumption. Dynamic simulation model of integrated system multiple heat and mass transfer processes in the whole DH system (district heating planning tool) has been developed on the basis of the proposed methodology.
6) Validation of the district heating planning tool has been performed for the DH system states in the period from 1999 to 2015. DH system: thermal capacities – water heating boilers 2 × 2.6 MW and cogeneration unit 0.6 MW_{th}, DH network total length of 1890 m, 23 consumers with a total heated area of 51069 m^2. All system energy data were available for the analysis from GIS based software. Analysis of data collected throughout the validation of the tool confirms reliability of the derived results with mean absolute deviation between the simulated and measured values (less than 8 %).
7) Nine efficiency and balance indicators with the recommended permissible limits have been proposed for the evaluation of six simulated DH system development scenarios. DHPT is found useful for the assessment of future development of any scale district heating systems with an unlimited number of scenarios and evidently indicates strengths and weaknesses of the considered development pathways.
8) Consistent simulations of the proposed future development scenarios for a particular DH system with different building renovation rate of 3 %, 5 %, and 7 % have shown natural reduction in thermal energy consumption in a 15-year perspective by 13.5 %, 22.5 % and 30 % (1380 MWh, 2301 MWh and 3068 MWh), respectively.
9) Simulation results of the last three scenarios, which consider the use of renewable energy sources, have shown that CO_2 emissions have been considerably reduced by about 40 % (from 3376 tCO_2 to around 2000 tCO_2 compared to the actual state), but the share of biomass has reached 47 % of the total fuel consumption for thermal energy production.
10) Detailed assessment of the results of these simulations has shown that the scenario of “realistic renovation and biomass use” is the most technologically advantageous one for a particular DH system with the payback period of 5.78 years (without the EU funding).

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