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Report on collection, evaluation and processing of data and information on Knowledge Platform

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1 Introduction to DH Knowledge Platform (www.dhknowledge.eu)

District Heating (DH) networks supply heat via a network of pipes carrying hot water as heat medium to consumers. The advantages of DH-systems are based on their high efficiency as well as their flexibility to combine different heat sources, which inheres a high potential for the transition of the heat sector in order reach national and international goals of reducing CO_2-emissions and contribute to mitigate climate change.

However, the potential and opportunities of DH-systems, yet not have been fully exploited by utilities and DH-system operators. Against this background, the overall concept of Low Temperature District Heating (LTDH) today, is an ongoing effort to reduce supply temperatures within existing and newly planned DH-systems at least below 80 °C in order to fully use the potential of DH-technology. LTDH can contribute significantly to integrate renewable energies as solar and geothermal heat as well as surplus heat into DH-systems and use energy resources more efficient by implementing "booster units" (e.g. heat pumps) at the consumer side.

In this regard, LTDH offers prospects for both the demand and the supply side and the utilisation of lower temperatures reduces heat losses within the DH-system. Besides the fact, that LTDH has a high potential for the transition of the heating sector towards low carbon emission or even carbon neutral heat supply, it also facilitates sector coupling (coupling between heating, electricity and mobility). Therefore, LTDH is not only a driver of transforming heating systems, but also goes along with the energy transition in general.

The District Heating Knowledge Platform was developed in the frame of the LowTEMP project, where 19 project partners from nine Baltic Sea Region (BSR) countries make district heating (DH) more sustainable by integrating low temperature district heating (LTDH) solutions in energy supply systems.

The DH Knowledge Platform (www.dhknowledge.eu) makes available a data repository on DH in BSR countries and a set of ICT tools to provide actors responsible for energy supply systems with basic knowledge that allows an insight into the necessity of future sustainable DH concepts.

It includes general descriptions on LTDH and environmental sustainability evaluation for LTDH, key parameters for DH evaluation, DH profiles for BSR countries, information on the development of LTDH strategies, financing schemes and business models and implemented LTDH case studies. The provided DH ranking and comparison tool helps to compare and analyze heat loads, the coefficient of Relative Importance of Losses (RiL) and the primary energy factor (PEFs) of different regions for the potential development of a LTDH strategy.

The DH Knowledge Platform is addressed to DH operators and engineers, urban planners and energy mangers in municipalities to get an overview on the status quo of existing DH situations in the BSR countries, LTDH implementation strategies and measures, and the energy efficiency of heat distribution processes or heat losses in the grids.

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1.1 The structure of Knowledge platform

As we can see from the picture below, the content of Knowledge platform is organised into 3 main sections: General Information; Evaluate DH performance and Moving towards low temperature DH. These sections focus on different target groups of system users.

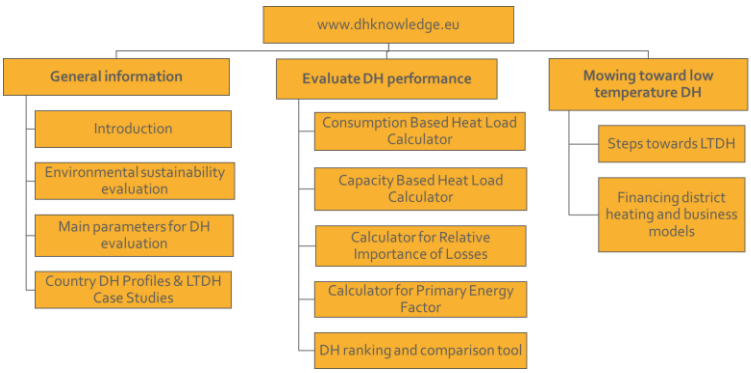

Fig. 1 Structure of knowledge platform

2 User groups of knowledge platform

There are three types of users that interact with the system: public users, content managers, and system administrator. Each of these three types of users has different access role of the system.

The public users can only view information provided by Knowledge platform. This means that the public user will be able to access read-only all public information without registration. The content managers can create, save and update the data collected in Knowledge platform and use different case modelling tools to provide the specific region related situations. The registrations is required for this type of users and only project partners (who collected data during project implementation) after complete registration can be content managers.

The administrator can manage overall system and the content manager user, add new functionalities and assign roles. The administrator of the knowledge platform is Klaipeda University.

2.1 Signing up into the system

Only registered and approved users can save data in the system. In order to sign up we choose Register from Menu and the following registration form opens where user name, e-mail address, and password should be entered:

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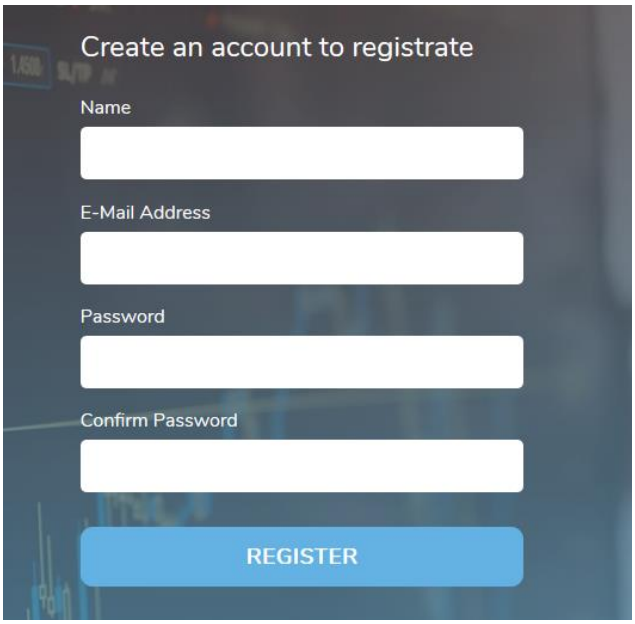

Fig. 2 User registration window

After registration the user name appears on the right of the menu which indicated that the user is logged on. By clicking user name the Log out option can be selected:

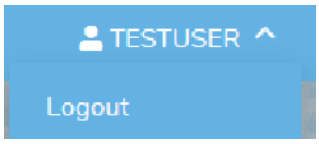

Fig. 3 Logged in user name

For a full access to data entry the new registered user should be approved by systems administrator. The system administrator sends a confirmation link to the user's email (which was provided during the registration). To finalize the approbation of the registered user you will get the following message to your email, where you need to click **Verify Email Address** button:

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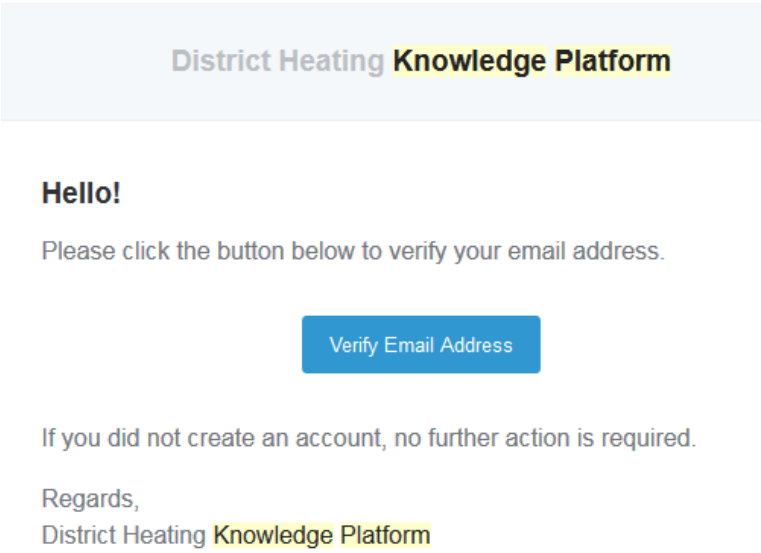

Fig. 4 Email, for registered user verification

The registered and approved user now can access the data entry forms, to save data into database, edit (user can only edit their own inputs), preview and delete data entries.

3 General information section

The **General information** section is oriented to all system users introducing and providing general description on low temperature DH systems, use of LCA for environmental sustainability assessment in DH system, description on main indicators and their meanings and georeferenced Graphs showing main indicators related to overall country DH systems and case studies.

The **Environment sustainability evaluation** subsection introduces life cycle assessment in district heating systems and how it can be used to assess the sustainability of DH systems and including examples and practical aspects of LCA role for sustainability assessment of DH systems.

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Fig. 5 Environment sustainability evaluation subsection

The **Main parameters for DH evaluation** subsection provides the description and importance of DH performance evaluation parameters such as operating hours, heat load, relative importance of losses, primary energy factor, the district heating global efficiency, operating temperature range of DH, consumption density.

Fig. 6 Main parameters for DH evaluation subsection

Country DH Profiles & Implemented LTDH Case Studies subsection provides information on the

general status quo of district heating (DH) systems and structures in the BSR countries. It contains knowledge about the efficiency of existing heating systems, heating demand, operators of the grid, available approaches and methods to implement low temperature district heating (LTDH). It also includes an overview on the status of smart energy supply systems and the use of renewables.

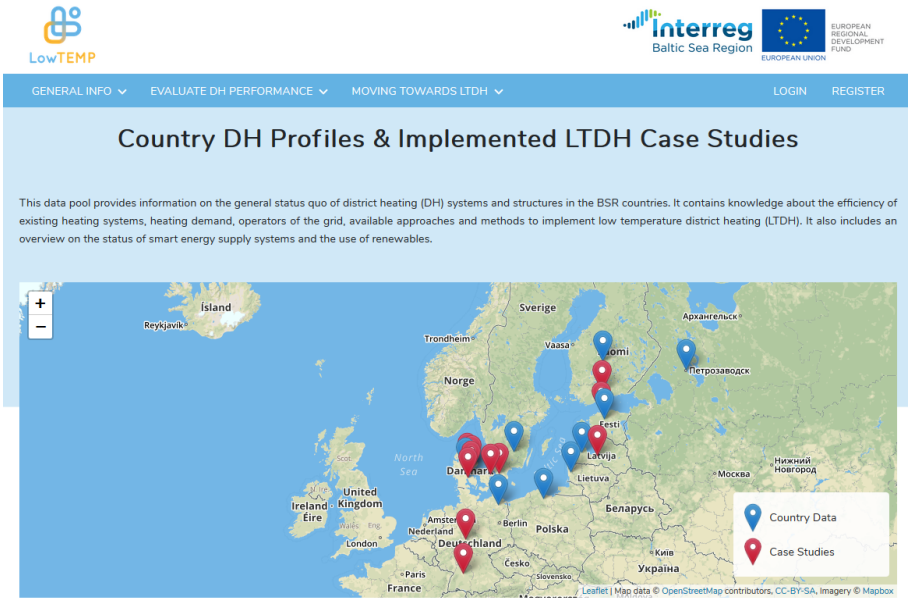

Fig. 7 Country DH profiles & implemented LTDH case studies subsection

The user in this subsection can access case studies and country data collected during LowTemp project implementation. By selecting appropriate marker on the map a system user can access the Country DH profile where an information on current district heating (DH) situation as regards institutional, organizational and technical framework conditions of the DH systems is provided. And the user can also compare situations in the BSR countries using interactive graphs, by selecting key indicators or regions of interest, where the bar charts provide more detailed information about the selected region.

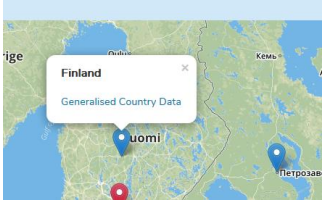

Fig. 8 Selecting generalised country data

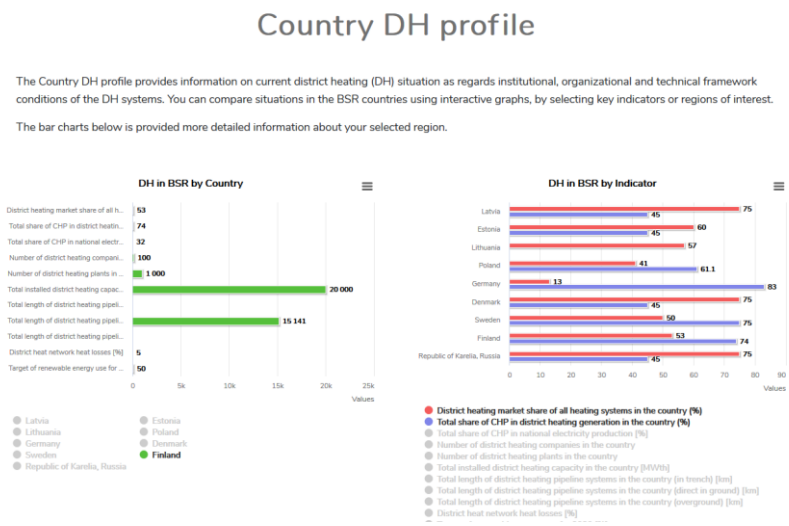

Fig. 9 Graphical representation of main DH indicators

And other more general information can be found below as well:

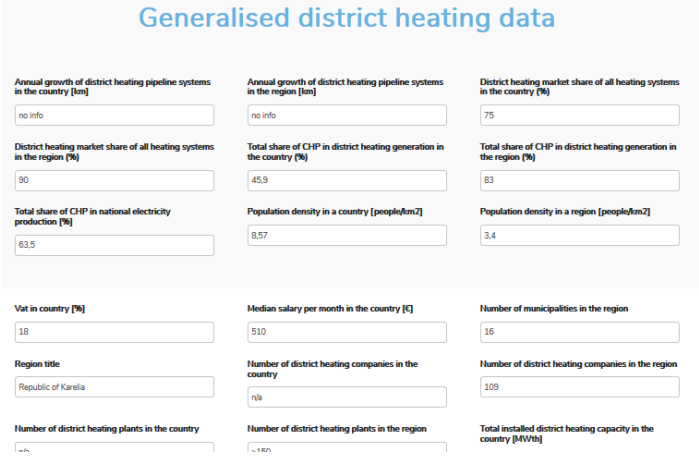

Fig. 10 Generalised data set (in a text form) for selected country

User can also preview the annotation of existing case study by selecting case study marker on the map and to click on Read more to get more details on this object:

Fig. 11 Annotation for selected case study

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4 Evaluate DH Performance Section

Evaluate DH performance sections is focused on target groups with expertise in DH (DH operators, heat producers). The following calculators can be used which can be accessed by public user i.e. there is no need to login into the system:

- Two heat load calculators based on different input datasets:
  - Consumption Based Heat Load Calculator;
  - Capacity Based Heat Load Calculator;
- Calculator for Relative Importance of Losses (RiL)
- Calculator for Primary Energy Factor (PEF)
- DH ranking and comparison tool

4.1 DH performance evaluation background from mathematical models

4.1.1 Technical indicators for DH performance evaluation

The description of any DH system began with the definition of technological parameters:

- Produced heat is the useful heat produced by centralised plants or a number of distributed heat producing units. This indicator is expressed in MWh per year and it is measured normally at the heat exchanger to the network/distribution infrastructure.
- Consumed heat is the final energy supplied to the final consumer's door for space heating and domestic hot water. It is the sum of final energy consumption in industry, households, services etc. This indicator is measured in MWh and refer to the calendar year.
- Heat losses in network are due to heat transmission in distribution pipe network. Heat losses are measured in MWh and it is the amount of heat in MWh that a pipe loses in the environment during the year.
- Supply and return temperatures of heat carrier (usually water) in supply and return pipeline of heat network are relevant for indicating generation of DH systems. This indicator is measured in °C. Low temperature distribution networks provides for normal distribution temperatures of 50-55 °C (supply pipe) and 20-25 °C (return pipe) as annual averages[1]. Supply/return temperature level can be shifted sometimes to 60/30.
- The installed capacity parameter covers all the total capacity of the heat producing units for heat production measured in MW.
- Other.

The largest range of parameters, which describe the DH system, are exactly technological parameters. Unfortunately, it is not possible to compare two different DH system using absolute parameters,

[1] Lund H, Werner S, Wiltshire R, Svendsen S, Thorsen J, et al. 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems. Energy 2014;68:1-11.

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therefore, it needs to use indicators that characterize an operation of the system.

There are indicators that describe separately different DH stages (heat source, heat network and end-users) and by analyzing there all together:

- **Specific heat losses** are heat losses divided on the heat produced and expressed as a percentage.
- **Specific fuel consumption** is relation between fuel consumed and produced heat in heat producing units measured in MWh/MWh.
- The classic **energy efficiency** indicator of heat production technologies is the efficiency coefficient (η). It is the relation of energy generated and the fuel invested at DH heat sources (boiler or cogeneration heat and power (CHP)). Promoting energy efficiency is the option for achieving positive change in district heating system. Efficiency coefficient is defined as

$$\eta = (H + E) / F \tag{1}$$

where F – total fuel used, MWh; E – total electricity generated, MWh; H – total heat produced, MWh[2].

- Solar collector efficiency is related with efficiency in energy conversion and transfer to a fluid in solar collector fields from available solar energy. Simply stated, collector efficiency is:

$$\eta = Q_{useful}/A_a I_a \tag{2}$$

where Quseful – rate of (useful) energy output, W; Aa - aperture area of the collector (m2); Ia – solar irradiance falling on collector aperture, W/m2[3].

- **Primary energy factor (PEF)** is energy indicator used for quantifying the primary energy use of a plant. PEF is defined as

$$f_{p,DH} = \frac{\sum_j E_j \cdot f_{P,j} + E_{aux} \cdot f_{P,el} - E_{CHP} \cdot f_{P,el}}{E_{del}} \tag{3}$$

where Ej – the amount of the jth primary energy consumed by the network; Eaux – the sum of auxiliary and pumping electric consumption; ECHP – the a mount of electricity provided by the CHP if any is installed; ƒp,j - the primary energy factor related to an energy source; ƒp,el - the primary energy factor for the power plants; Edel - the amount of energy delivered to the consumers4.

- The use of the **primary resource factor (PRF)**[5] enables to measure the savings and losses occurring from energy generation to the delivery to the building. The primary resource factor fP expresses the ratio of the non-regenerative resource energy Q_P required for the building to the final energy supplied to the building Q_E.

[2] Boiler efficiency guide. CleaverBook Ink. 2010.
[3] Available: http://www.powerfromthesun.net/Book/chapter05/chapter05.html
[4] Pacot P.E, Reiter S. Quality indicators for district heating networks. Local Environment: Management & Analysis (LEMA), University of Liege, Liege, Belgium
[5] Intelligent Energy Europe project "ECOHEATCOOL", Work package 3, Guidelines for assessing the efficiency of district heating and district cooling systems. Available: https://www.euroheat.org/wp-content/uploads/2016/02/Ecoheatcool_WP3_Web.pdf

$$f_p = \frac{Q_P}{Q_E} \tag{4}$$

- **primary resource factor (PRF)** for DH system with CHP

$$f_{P,DH} = \frac{\sum_j Q_{F,i} \cdot f_{P,Fi} + W_{CHP} \cdot F_{P,elt}}{\sum_j Q_{C,j}} \tag{5}$$

where $Q_{F,i}$ - Fuel (final energy) input to the heating plants and to the cogeneration plants within the considered system within the considered period (usually one year). The amount of this energy is measured at the point of delivery.
$f_{P,F,i}$ - Primary resource factor of the fuel (final energy) inputs.
W_{CHP} - Electricity production of the cogeneration plants of the considered system.
$f_{P,elt}$ - Primary resource factor of electrical power. This factor is given by the European average - in accordance to principles laid down in annex III of Directive 2004/08/EC – c_f.
$Q_{C,i}$ - Heat energy consumption measured at the primary side of the substations of the supplied customers within the period of interest (usually one year).

- The amount **of primary energy savings (PES)** provided by cogeneration production defined in accordance with Directive 2012/27/EU of the European Parliament and the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU shall be calculated on the basis of the following formula:

$$PES = \left[1 - \frac{1}{\frac{CHPH_\eta}{\mathrm{Re}\ fH_\eta} - \frac{CHPE_\eta}{\mathrm{Re}\ fH_\eta}} \right] \tag{6}$$

where CHP H_η is the heat efficiency of the cogeneration production defined as annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration. Ref H_η is the efficiency reference value for separate heat production. CHP E_η is the electrical efficiency of the cogeneration production defined as annual electricity from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration. Ref E_η is the efficiency reference value for separate electricity production.

- The **capacity utilization factor** is used for cross-referencing of the heating company's operation:

$$A_n = \frac{N_N}{N_{uz}} \tag{7}$$

where N_N - power requirement during heating season, MW; N_{uz} - installed capacity of the company, MW**Klaida! Žymelė neapibrėžta.**.

- **The efficiency of heat pumps** is indicated by its coefficient of performance (COP). The COP is the ratio between energy usage of the compressor and the amount of useful heat extracted

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from the condenser[6]. A high COP value represents a high efficiency. COP is defined as

$$COP = \frac{Q}{W} \tag{8}$$

where Q – useful heat, kW; W – electricity consumption by unit, kW[6].

- **Power-to-heat ratio** is one more efficiency measure[7].

$$\alpha = \frac{E}{H} \tag{9}$$

- Technological indicators for transmission-distribution network
- The most significant effect connected with decrease of heat losses in transmission-distribution network that decrease primary energy consumption. Heat received by the consumers is calculated by:

$$H = G \cdot c \cdot \Delta T \tag{10}$$

where H - heat supplied to network, MWh/year; c - volume specific heat capacity, MWh/m³K; $\Delta T = T_{supply} - Tr_{return}$, temperature difference, K; G – volume flow of heat carrier, m³/year.

Generally, the temperatures for a district heating network are kept as low as possible in order to reduce heat losses and increase efficiency of electricity co-production, but temperature difference ΔT need to retain the same as by high temperature regime. Unfortunately, ΔT decrease (Table 1) [8].

Table 1[8] Current and future temperature sets for DH networks

Network type	Media	DH forward temperature	DH return temperature
Transmission	H_2O	110 °C	55 °C
Old distribution	H_2O	90 °C	45 °C
New distribution	H_2O	70 °C	35 °C
4GDH	H_2O	40 °C	20 °C

Volume flow can be increased by decreasing temperature difference between supply and return heat carrier. It means that power consumption for pumping heat carrier can raise.

- Consumption of electric power for transmission (N_{el}) is determined according to the necessary heat consumption

$$N_{el} = \frac{t_d \cdot \rho \cdot g \cdot G \cdot H}{\eta} \tag{11}$$

[6] DECISIONS COMMISSION DECISION of 1 March 2013 establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council

[7] Frederiksen S, Werner S. District Heating and cooling. Studentliteratur AB,Lund, 2017

[8] Ommen T, Markkussen W.B, Elmegaard B. Lowering district heating temperatures – Impact to system performance in current and future Danish energy scenarios. Energy 2016;94:273-291

where ρ – heat carrier density, kg/m³; g – standard gravity, m/s²; G_s – heat carrier flow, m³/s; H - total pressure drop, m; η - efficiency of pump.

Specific electric power consumption for heat transmission is ratio between consumption of electric power for transmission and heat consumption measured in kWh/MWh.

- Specific heat losses for each pipe segment[9], q_L W/m.
- Heat losses in network are due to heat transmission in distribution pipe network during the year in %[7]:

$$q_{los} = \frac{H_{los}}{H} \cdot 100\% \tag{12}$$

where H_{los} – total heat losses in network, MWh per year; H – heat supplied to network, MWh per year.

- Linear heat density of the DH system indicator is the produced heat sold per unit of length of the distribution network measured in MWh/m per year[10].

4.1.2 Heat load calculation and heat duration curve construction

4.1.2.1 *Method 1*

If initial data from municipalities are collected as transferred heat to the network per month (MWh per month) than there is possibility to use Method 1. Necessary data and formulas for heat load calculation and heat duration curve construction are showed below.
Step 1 is to collect annual data from heat source of produced heat of each month in MWh

Table 2 Produced heat during the year

Symbol	Variable	Example	Unit
Qjan	Transferred heat to the network in January	1207,59	MWh
Qfeb	Transferred heat to the network in February	1325,19	MWh
Qmar	Transferred heat to the network in March	1022,45	MWh
Qapr	Transferred heat to the network in April	459,78	MWh
Qmay	Transferred heat to the network in May	118,10	MWh
Qjun	Transferred heat to the network in June	93,50	MWh
Qjul	Transferred heat to the network in July	86,72	MWh
Qaug	Transferred heat to the network in August	94,03	MWh
Qsept	Transferred heat to the network in September	102,30	MWh
Qoct	Transferred heat to the network in October	402,98	MWh
Qnov	Transferred heat to the network in November	755,45	MWh
Qdec	Transferred heat to the network in December	989,79	MWh

[9] Dalla Rosa A, Li H, Svendsen S. Method for design of pipes for Low-energy district heating, with focus on heat losses. Energy 2011;36:2407-2418
[10] Dalla Rose A, Christensen J.E. Low-energy district heating in energy-efficient building areas. Energy 2011;36:6890-6899

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Table 3 Hours per month

Symbol	Variable	Example	Unit
hjan	Hours in January	744	h
hfeb	Hours in February	672	h
hmar	Hours in March	744	h
hapr	Hours in April	720	h
hmay	Hours in May	744	h
hjun	Hours in June	720	h
hjul	Hours in July	744	h
haug	Hours in August	744	h
hsept	Hours in September	720	h
hoct	Hours in October	744	h
hnov	Hours in November	720	h
hdec	Hours in December	744	h

Step 2 is to calculate heat capacity of each month in MW (Table 4).

Table 4 Heat capacity calculation

Symbol	Calculation	Variable	Example	Unit
Njan	=Qjan/hjan	Heat capacity in January	1,62	MW
Nfeb	=Qfeb/hfeb	Heat capacity in February	1,97	MW
Nmar	=Qmar/hmar	Heat capacity in March	1,37	MW
Napr	=Qapr/hapr	Heat capacity in April	0,64	MW
Nmay	=Qmay/hmay	Heat capacity in May	0,16	MW
Njun	=Qjun/hjun	Heat capacity in June	0,13	MW
Njul	=Qjul/hjul	Heat capacity in July	0,12	MW
Naug	=Qaug/haug	Heat capacity in August	0,13	MW
Nsept	=Qsept/hsept	Heat capacity in September	0,14	MW
Noct	=Qoct/hoct	Heat capacity in October	0,54	MW
Nnov	=Qnov/hnov	Heat capacity in November	1,05	MW
Ndec	=Qdec/hdec	Heat capacity in December	1,33	MW

Step 3 is to calculate average hot water heat load in MW. Example can be seen in Table 5

Table 5 Average hot water heat load calculation

Symbol	Calculation	Variable	Example	Unit
Nhw	=(Qmay/hmay+Qjun/hjun+Qjul/hjul+ Qaug/haug+Qsept/hsept)/5	Average hot water heat load	0,13	MW

Collected average outdoor temperatures of each month in °C can be seen in Table 6.

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Table 6 Average outdoor temperatures

Symbol	Variable	Example	Unit
tjan	Average outdoor temperature in January	-2,01	°C
tfeb	Average outdoor temperature in February	-6,99	°C
tmar	Average outdoor temperature in March	0,80	°C
tapr	Average outdoor temperature in April	7,84	°C
tmay	Average outdoor temperature in May	12,54	°C
tjun	Average outdoor temperature in June	18,63	°C
tjul	Average outdoor temperature in July	21,13	°C
taug	Average outdoor temperature in August	17,89	°C
tsept	Average outdoor temperature in September	14,26	°C
toct	Average outdoor temperature in October	8,40	°C
tnov	Average outdoor temperature in November	4,70	°C
tdec	Average outdoor temperature in December	2,11	°C

Step 4 is to make scatter chart, add trendline and display equation on chart. Data for scatter chart can be seen in Table 7 and scatter chart example with equation in Fig. 12.

Table 7 Data for scatter chart

Average outdoor temperature, °C		Heat capacity in heating season, MW	
Symbol	Example	Symbol	Example
tjan	-2,01	Njan	1,62
tfeb	-6,99	Nfeb	1,97
tmar	0,80	Nmar	1,37
tapr	7,84	Napr	0,64
toct	8,40	Noct	0,54
tnov	4,70	Nnov	1,05
tdec	2,11	Ndec	1,33

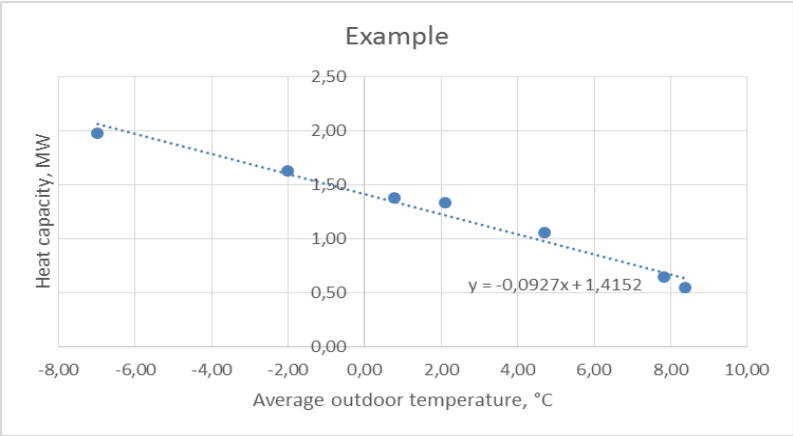

Fig. 12. Heat capacity at average outdoor temperature in heating season (example)

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Table 8 Average outdoor temperatures for heat load calculation.

Symbol	Temperature	Variable	Unit
t8	8,00	Outdoor temperature	°C
t5	5,00	Outdoor temperature	°C
to	0,00	Outdoor temperature	°C
t-5	-5,00	Outdoor temperature	°C
t-10	-10,00	Outdoor temperature	°C
t-15	-15,00	Outdoor temperature	°C
t-20	-20,00	Outdoor temperature	°C
t-25	-25	Outdoor temperature	°C

Step 5 is to calculate heat load at determined outdoor temperatures using equation from the chart (Table 9).

Table 9 Heat load

Symbol	Calculations	Variable	Example	Unit
Nhw	=Nhw (Step 3)	Hot water heat load	0,13	MW
Nhw	=Nhw (Step 3)	Hot water heat load	0,13	MW
N8	=a*t8+b	Heat load at 8 °C	0,67	MW
N5	=a*t5+b	Heat load at +5 °C	0,95	MW
No	=a*to+b	Heat load at 0 °C	1,42	MW
N-5	=a*t-5+b	Heat load at -5 °C	1,88	MW
N-10	=a*t-10+b	Heat load at -10 °C	2,34	MW
N-15	=a*t-15+b	Heat load at -15 °C	2,81	MW
N-20	=a*t-20+b	Heat load at -20 °C	3,27	MW
N-25	=a*t-25+b	Heat load at -25 °C	3,73	MW

Step 6 is to make heat duration curve (scatter chart) using data from Table 10. Example of heat duration curve can be seen in Fig. 13.

Table 10 Operating hours

Symbol	Variable	Variable	Unit	Symbol	Example	Unit
h83	8760,00	Operating hours	h	Nhw	0,13	MW
h82	4872,00	Operating hours	h	Nhw	0,13	MW
h8	4872,00	Operating hours	h	N8	0,67	MW
h5	3989,00	Operating hours	h	N5	0,95	MW
ho	2835,00	Operating hours	h	No	1,42	MW
h-5	1050,00	Operating hours	h	N-5	1,88	MW
h-10	518,00	Operating hours	h	N-10	2,34	MW
h-15	305,00	Operating hours	h	N-15	2,81	MW
h-20	104,00	Operating hours	h	N-20	3,27	MW
h-25	14	Operating hours	h	N-25	3,73	MW

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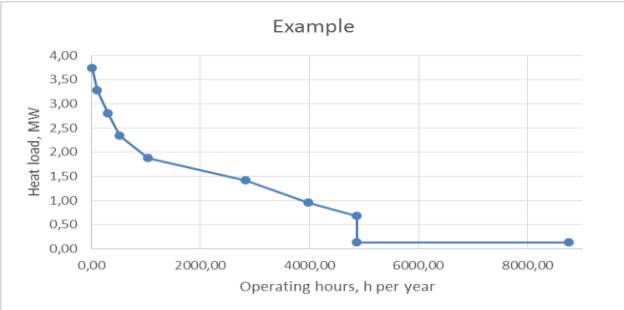

Fig. 13. Example of heat duration curve

4.1.2.2 Method 2

If initial data from municipality are collected as heat load for heating, hot water preparation, heat losses in distribution network and other (industrial consumers load etc.) by average outdoor temperature of the region in heating season than is possibility to use Method 2.

Step 1 is to collect data of heating, hot water and heat losses capacity at average outdoor temperature of the region in heating season (example are shown in Table 11). Average outdoor temperature is 0 °C for example.

Table 11 Data of heating, hot water and heat losses capacity at average outdoor temperature of the region

Symbol	Variable	Example	Unit
Nave	Heating capacity at average outdoor temperature	1,13	MW
N2hw	Hot water capacity at average outdoor temperature	0,12	MW
Nl	Heat losses capacity at average outdoor temperature	0,17	MW

Step 2: Average outdoor temperature of the region should be determined. Data of temperatures for heat load calculation are shown in Table 12. Average outdoor temperature of the region is 0 °C for an example, but other variables are determined and should not be changed in the Table 12.

Table 12 Data of temperatures

Symbol	Temperature	Variable	Unit
tao	0	Average outdoor temperature of the region	°C
tar	18	Average room temperature	°C
t8	8	Outdoor temperature	°C
t5	5	Outdoor temperature	°C
to	0	Outdoor temperature	°C
t-5	-5	Outdoor temperature	°C
t-10	-10	Outdoor temperature	°C
t-15	-15	Outdoor temperature	°C
t-20,7	-20,7	Outdoor temperature	°C
t-25	-25	Outdoor temperature	°C

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Step 3 is calculation of correction coefficients at corresponding outdoor temperatures (formulas are shown in Table 13).

Table 13 Calculation of correction coefficient

Name	Calculation of correction coefficient	Example
k8	=(tar-t8)/(tar-tao)	0,56
k5	=(tar-t5)/(tar-tao)	0,72
ko	=(tar-to)/(tar-tao)	1,00
k-5	=(tar-'t-5')/(tar-tao)	1,28
k-10	=(tar-'t-10')/(tar-tao)	1,56
k-15	=(tar-'t-15')/(tar-tao)	1,83
k-20,7	=(tar-'t-20,7')/(tar-tao)	2,15
k-25	=(tar-'t-25')/(tar-tao)	2,39

Step 4 is calculation of total heat load at determined outdoor temperatures. In this case only heating capacity is calculated at determined outdoor temperatures and other two capacities (hot water and heat losses) are the same as in Table 11. Formulas are shown in Table 14.

Table 14 Calculation example

Name	Calculation	Variable	Example	Unit
N2hw	=N2hw	Hot water only heat load	0,12	MW
N2hw	=N2hw	Hot water only heat load	0,12	MW
N28	=Nave*k8+Nhw+Nl	Heat load at 8 °C	0,91	MW
N25	=Nave*k5+Nhw+Nl	Heat load at +5 °C	1,10	MW
N20	=Nave*ko+Nhw+Nl	Heat load at 0 °C	1,42	MW
N2-5	=Nave*'k-5'+Nhw+Nl	Heat load at -5 °C	1,73	MW
N2-10	=Nave*'k-10'+Nhw+Nl	Heat load at -10 °C	2,04	MW
N2-15	=Nave*'k-15'+Nhw+Nl	Heat load at -15 °C	2,35	MW
N2-20,7	=Nave*'k-20,7'+Nhw+Nl	Heat load at -20,7 °C	2,71	MW
N2-25	=Nave*'k-25'+Nhw+Nl	Heat load at -25 °C	2,98	MW

Step 5 is to make heat duration curve (scatter chart) using data from Table 15. Example of heat duration curve can be seen in Fig. 14.

Table 15 Calculation example

Symbol	Variable	Variable	Unit	Symbol	Example	Unit
h83	8760,00	Operating hours	h	N2hw	0,12	MW
h82	4872,00	Operating hours	h	N2hw	0,12	MW
h8	4872,00	Operating hours	h	N28	0,91	MW
h5	3989,00	Operating hours	h	N25	1,10	MW
ho	2835,00	Operating hours	h	N20	1,42	MW
h-5	1050,00	Operating hours	h	N2-5	1,73	MW

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h-10	518,00	Operating hours	h	N2-10	2,04	MW
h-15	305,00	Operating hours	h	N2-15	2,35	MW
h-20,7	104,00	Operating hours	h	N2-20,7	2,71	MW
h-25	14	Operating hours	h	N2-25	2,98	MW

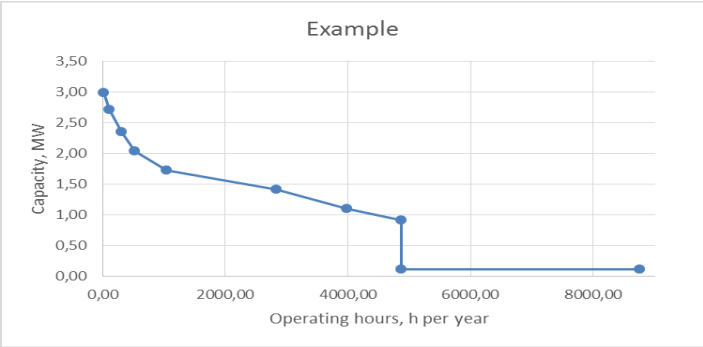

Fig. 14 Example of heat duration curve

4.1.3 Primary energy factor (PEF)

The Primary energy factor (PEF) is calculated by using the methodology described in the European Standard EN 15316-4-5. Formula 13 shows the calculation of primary energy factor $f_{P,DH}$ of the district heating system:

$$f_{P,DH} = \frac{\sum Q_{F,j} \cdot f_{P,F,I} - W_{CHP} \cdot f_{P,elt}}{\sum Q_{C,j}} \tag{13}$$

where $Q_{F,j}$ - Fuel (final energy) input to the heating plants and to the cogeneration plants within the considered system within the considered period (usually one year). The amount of this energy is measured at the point of delivery in MWh (calculation is shown in Table 16);

$f_{P,F,j}$ - Primary energy factor of the fuel (final energy) inputs. Values from Table 17 can be used as informative values;

W_{CHP} - Electricity production of the cogeneration plants of the considered system in MWh;

$f_{P,elt}$ - Primary energy factor of electrical power. This factor is given by the European average (informative value in Table 17);

$Q_{C,I}$ - Heat energy consumption measured at the primary side of the dwelling substations of the supplied buildings within the period of interest (usually one year) in MWh (calculation is shown in Table 18).

Table 16 Fuel input to the HP and CHP

Symbol	Variable	Example	Unit
Fjan	Fuel input to the HP and CHP in January	1509,49	MWh
Ffeb	Fuel input to the HP and CHP in February	1656,49	MWh
Fmar	Fuel input to the HP and CHP in March	1278,06	MWh
Fapr	Fuel input to the HP and CHP in April	574,73	MWh
Fmay	Fuel input to the HP and CHP in May	147,63	MWh
Fjun	Fuel input to the HP and CHP in June	116,88	MWh
Fjul	Fuel input to the HP and CHP in July	108,40	MWh
Faug	Fuel input to the HP and CHP in August	117,54	MWh
Fsept	Fuel input to the HP and CHP in September	127,88	MWh
Foct	Fuel input to the HP and CHP in October	503,73	MWh
Fnov	Fuel input to the HP and CHP in November	944,31	MWh
Fdec	Fuel input to the HP and CHP in December	1237,24	MWh
QF,j	Annual fuel input to the HP and CHP	8322,35	MWh

Table 17 Primary energy factor of the fuel and electrical power

Symbol	Fuel	Primary Energy Factor
fP,F,i	Lignite Coal	1,3
fP,F,i	Hard Coal	1,2
fP,F,i	Oil	1,1
fP,F,i	Natural Gas	1,1
fP,F,i	Excess heat e.g. from industrial proc.	0,05
fP,F,i	Regenerative Energies (e.g. Wood)	0,1
fP,F,i	Waste as Fuel, Landfill Gas	0
fP,elt	Electrical Power, European Average	2,5

Table 18 Example of heat consumptions

Name	**Variable**	**Example**	**Unit**
Q2jan	Consumed heat in january	1132,85	MWh
Q2feb	Consumed heat in february	1208,06	MWh
Q2mar	Consumed heat in march	914,68	MWh
Q2apr	Consumed heat in april	391,74	MWh
Q2may	Consumed heat in may	102,57	MWh
Q2jun	Consumed heat in june	80,06	MWh
Q2jul	Consumed heat in jule	73,29	MWh
Q2aug	Consumed heat in august	81,55	MWh
Q2sept	Consumed heat in september	88,94	MWh
Q2oct	Consumed heat in october	349,19	MWh
Q2nov	Consumed heat in november	666,42	MWh
Q2dec	Consumed heat in december	931,60	MWh
Edel	Consumed heat per year	6020,95	MWh

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4.1.4 The relative importance of losses (RiL)

The relative importance of losses (RiL) definition is given by equation (14):

$$RiL = \frac{E_{loss} + E_{aux}}{E_{del}} \tag{14}$$

where

E_{loss} – Amount of energy lost in the district heating e.g. thermal loss through pipes, water replenishment, etc. in MWh (calculation is shown in Table 19).

E_{aux} - Amount of electricity needed to deliver power and heat to the consumers (e.g. pump consumption, lighting of the heat plant in MWh.

E_{del} - Amount of energy delivered to the consumers in MWh (calculation is shown in Table 18).

Table 19 Example of heat losses

Name	Calculation	Variable	Example	Unit
Q3jan	=Qjan-Q2jan	Heat losses in january	74,74	MWh
Q3feb	=Qfeb-Q2feb	Heat losses in february	117,13	MWh
Q3mar	=Qmar-Q2mar	Heat losses in march	107,77	MWh
Q3apr	=Qapr-Q2apr	Heat losses in april	68,04	MWh
Q3may	=Qmay-Q2may	Heat losses in may	15,53	MWh
Q3jun	=Qjun-Q2jun	Heat losses in june	13,44	MWh
Q3jul	=Qjul-Q2jul	Heat losses in july	13,43	MWh
Q3aug	=Qaug-Q2aug	Heat losses in august	12,48	MWh
Q3sept	=Qsept-Q2sept	Heat losses in september	13,36	MWh
Q3oct	=Qoct-Q2oct	Heat losses in october	53,79	MWh
Q3nov	=Qnov-Q2nov	Heat losses in november	89,03	MWh
Q3dec	=Qdec-Q2dec	Heat losses in december	58,19	MWh
Eloss	=SUM(Q3jan:Q3dec)	Annual heat losses	636,93	MWh

4.1.5 Implementation of different aspects to development of LTDH strategy by using results of multi-criteria analysis

The significant reduction in building energy use and the need for a wider exploitation of waste heat and renewable energy, however, mean that current DH technologies become barriers to any further increase in the market share. When building heating demand drops to one-quarter of the current level, the relative heat loss along the current DH network becomes unacceptably high. The immediate and effective solution is to reduce the temperature level in the network.

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Low-temperature DH system have many advantages for all DH stages[11]:

Heat source

- Improved power-to-heat ratio in steam CHP plants;
- Increased utilisation from flue gas condensation;
- Higher coefficient of performances in heat pumps;
- Higher conversion efficiencies in solar collector fields;
- Reduced heat loss in thermal storage units.

Heat network

- Reduced network heat loss;
- Reduced pipeline thermal stress;
- Other pipe materials possible.

Heat consumers

- Improved quality match between heat supply and heat demand;
- Optimal bill for consumed heat.

The low-temperature DH system need to be researched by using coherent approach because it gives benefits to the whole system. The technological, economic and environmental etc. indicators described above are analysed by multi-criteria analyses method in order to evaluate various DH system scenario and find the most suitable for development of system[12]. Multi-criteria analyses provide an opportunity to evaluate different criteria qualitative and quantitative from different stakeholders' point of view.

Wang et.al. reviewed the corresponding methods in different stages of multi-criteria decision-making for sustainable energy, i.e., criteria selection, criteria weighting, evaluation, and final aggregation [13].

Based on identified advantages of DH system multi-criteria analysis matrix with nine criteria was created:

1. Specific fuel consumption, MWh/MWh (X1j);
2. Power to heat ratio, (X2j);
3. Specific heat consumption for heating per m2 (X3j);
4. RES share % (X4j);
5. Legal regulation of Low-temperature DH (X5j);
6. Specific heat losses in network, kWh/MWh (heat input to distribution network)) (X6j);
7. Specific CO_2 emissions, t CO_2(fuel)/MWh (heat input to distribution network) (X7j);

[11] Dalla Rosa A, Li H, Svendsen S, Werner S, Persson U, Ruehling K. Annex X Final Report: Toward 4th Generation District Heating. Experience and Potential of Low-Temperature District Heating , 2014-09-01
[12] Ziemele J, Pakere I, Talcis N, Blumberga D. Multi-criteria analysis of district heating system in Baltic States. Energy Procedia 2014;61:2172-2175
[13] Wang J-J, Jing Y-Y, Zhang Z-F, Zhao J-H. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and Sustainable Energy Reviews 2009; 13: 2263–2278

8. Specific power consumption, kWh/MWh (heat input to distribution network) (X8j);
9. Affordability of DH heat, % (X9j).

Table 20 Overview of evaluation criteria

DH municipality	Criteria								
	X1i	X2i	X3i	X4i	X5i	X6i	X7i	X8i	X9i
A1									
A2									
…									

As a result, is created a matrix where Ai are the analyzed objects, i = 1,…,n; Xij is the qualitative or quantitative analysis criterion, i = 1,…,7; x_{ij}^{k} indicates the evaluation of the object Ai for the decision maker k.
In order to perform this task, a multi-attribute or multi-criteria decision making (MADM/MCDM) method and its instrument – TOPSIS - are used [14]. Subsequent calculation steps are shown in Fig. 15.

[14] Hwang C.L, Yoon K. Multiple Attribute Decision Making – Method and Applications. Berlin: Springer-Verlag; 1981

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Step 1: Construction normalized decision matrix.
to normalize the parameter x_{ij}, which we wish to maximize:

$$r_{ij}^{k} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \quad (18)$$

where r_{ij}^{k} is the normalized parameter.
To normalize the parameter x_{ij}, which we wish to minimize:

$$r_{ij}^{k} = \frac{maxx_{ij} - x_{ij}}{maxx_{ij} - minx_{ij}} \quad (19)$$

Step 2: Construct the weighted normalized decision matrix.

$$v_{ij} = w_j r_{ij} \quad (20)$$

where w_j is weight for j criterion and $\sum_{j=1}^{n} w_j = 1$.

Step 3: Determine the positive and negative ideal solution.

$$A^{+} = \{v_1^{+}, \ldots, v_n^{+}\} = \{(max_i v_{ij} | j \in J), (min_i v_{ij} | j \in J'')\} \quad (21)$$

$$A^{-} = \{v_1^{-}, \ldots, v_n^{-}\} = \{(min_i v_{ij} | j \in J), (max_i v_{ij} | j \in J'')\} \quad (22)$$

where J pertains to the criteria to be maximized (benefit attributes) and J'' pertains to the criteria to be minimized (cost attributes).

Step 4: Calculate the separation from each solution.
The separation from positive ideal solution (S^{+}) is:

$$S_i^{+} = [\sum_{j=1}^{n} (v_{ij} - v_j^{+})]^{1/2} \quad (23)$$

The separation from the negative ideal solution (S^{-}) is:

$$S_i^{-} = [\sum_{j=1}^{n} (v_{ij} - v_j^{-})]^{1/2} \quad (24)$$

where i in equations (15) and (16) is the ranking position for the heating company being considered. which can change from 1 to 26.

Step 5: Calculation the relative closeness to the ideal solution C_i^{*}

$$C_i^{+} = S_i^{-} / (S_i^{+} + S_i^{-}) \quad (25)$$

Fig. 15 Stepwise procedure for performing TOPSIS methodology

Obtained results show efficiency of performance of municipalities DH systems. Results are ranked from smaller to largest for better visualization (Fig. 16). The municipality DH performance efficiency indicator determined by the TOPSIS method can fall between 0 and 1. Four efficiency zones have been developed in Fig. 16. The performed analysis indicates that best municipalities have modernized their systems in recent years and could introduce low-temperature DH system. In studying all municipalities achieved criteria in more detail, could be established the strengths and weaknesses for low-temperature DH implementation.

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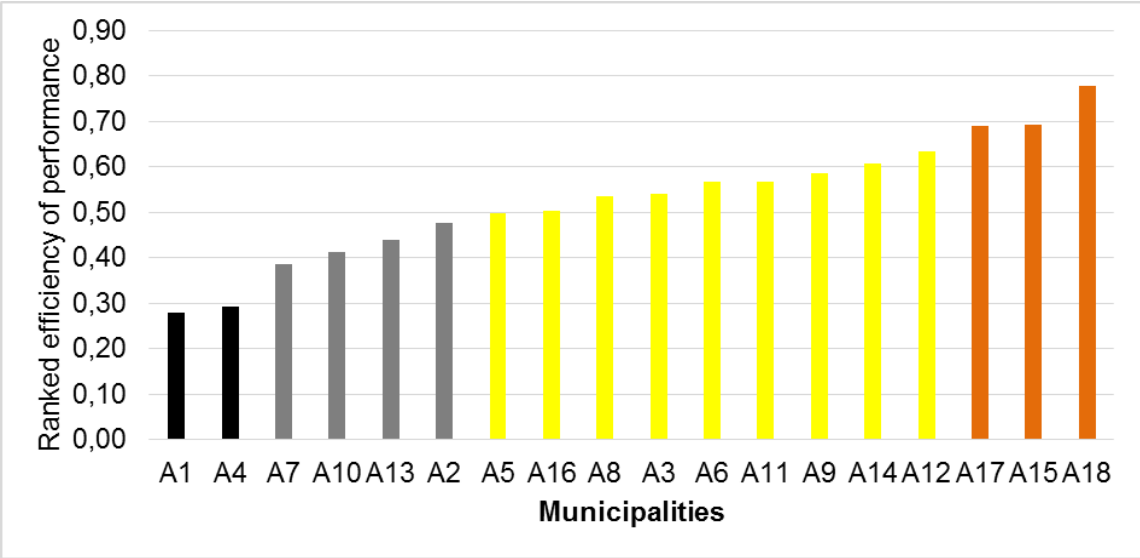

Fig. 16. Efficiency of municipalities relative to their closeness to the ideal solution

4.2 Consumption Based Heat Load Calculator

(*Evaluate DH performance -> Consumption Based Heat Load Calculator*)

This calculator finds the optimal capacities for an existing or new to design boiler house. It presents the correlation between outdoor temperature and transferred heat to the network. This information can be used to control the transferred heat and thus to increase the energy efficiency. Heat load calculation in this tool considers:

- heating season
- transferred heat to network
- hours in a month
- average outdoor temperature
- total operating hours in a year at appropriate outdoor temperature

The main users of this calculator can be DH operators, DH engineers, urban planner and energy managers in municipalities, to have an overview about the transferred heat of heat distribution processes and thus to increase the energy efficiency.

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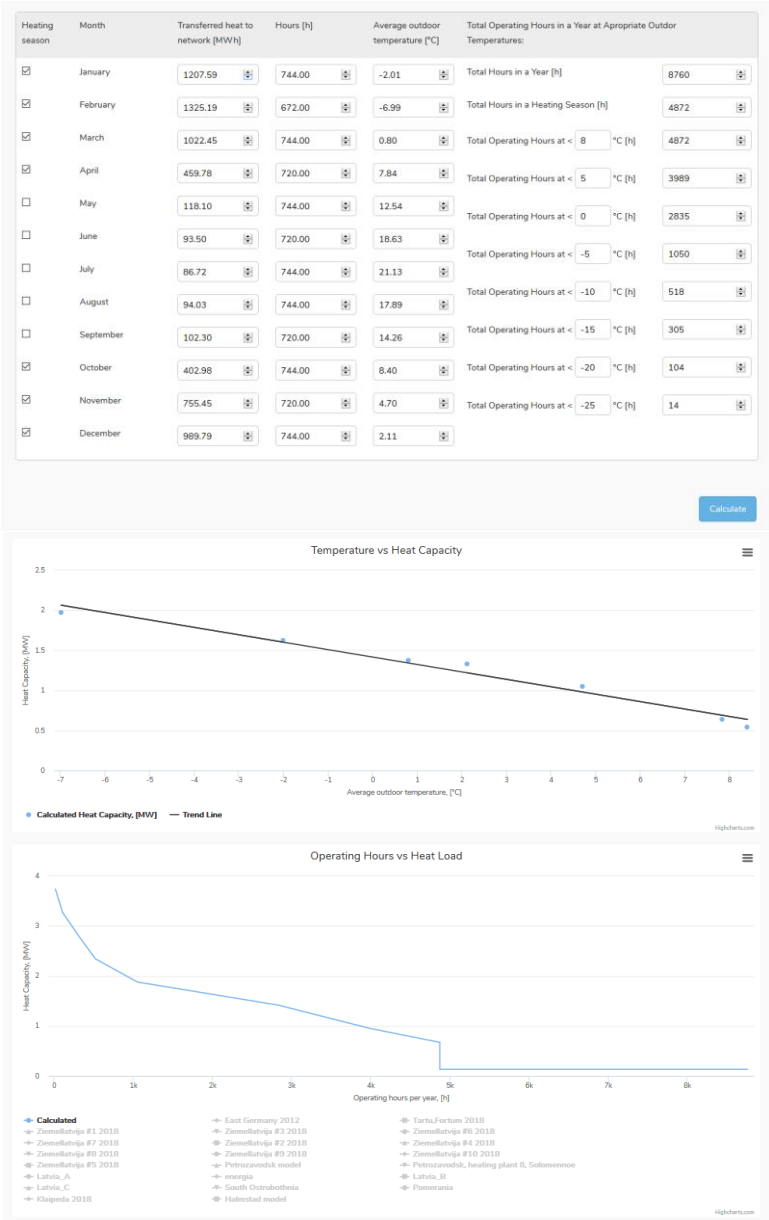

Fig. 17 Consumption Based Heat Load Calculator

To calculate the heat load by using this approach the following parameters should be indicated:

1. By ticking determine if the corresponding month belonged to the heating season.
2. Transferred heat to network in MWh in a corresponding month.
3. Hours in a corresponding month (number_of_days_in_a_month ×24).
4. Average outdoor temperatures of each month in °C.
5. Total operating hours in a year at appropriate outdoor temperature. The temperature range must be selected according to the regional climate conditions and national regulations to cover the typical temperature range of the heating season.

All the input fields must be filled in to make the calculation run. The calculation results are represented

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in two graphs: average outdoor temperature vs heat capacity and annual operating hour vs heat load. The user by selecting other dataset can compare the result with existing calculations stored in database

4.3 Capacity Based Heat Load Calculator

(*Evaluate DH performance -> Capacity Based Heat Load Calculator*)

This calculator finds the capacities for an existing or new to design boiler house. It allows for finding the heat load curve. It presents the correlation between outdoor temperature and transferred heat to the network. This information can be used to control the transferred heat and thus to increase the energy efficiency. Heat load calculation in this tool considers:

- Heating capacity at average outdoor temperature
- Hot water capacity at average outdoor temperature
- Heat losses capacity at average outdoor temperature
- Average outdoor temperature
- Average room temperature
- Total operating hours in a year at appropriate outdoor temperature.

The main users of this calculator can be DH operators, DH engineers, urban planners and energy managers in municipalities to have an overview about the transferred heat of heat distribution processes and thus to increase the energy efficiency.

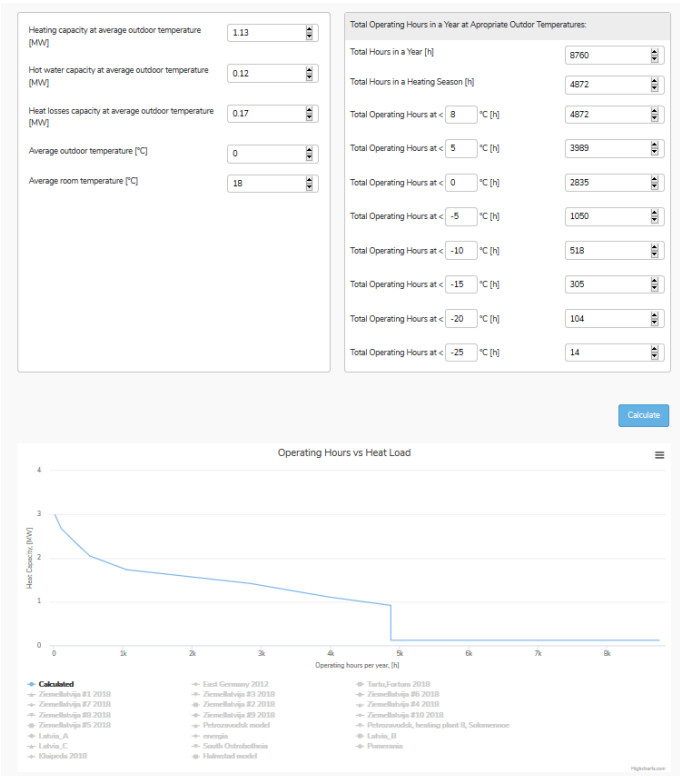

Fig. 18 Capacity Based Heat Load Calculator

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To calculate the heat load by the second approach the following parameters should be indicated:

1. Heating capacity at average outdoor temperature
2. Hot water preparation capacity at average outdoor temperature
3. Heat losses capacity at average outdoor temperature
4. Average outdoor temperature of the region
5. Average room temperature
6. Total operating hours in a year at appropriate outdoor temperature. The temperature range must be selected according to the regional climate conditions and national regulations to cover the typical temperature range of the heating season

All the input fields must be filled in to make the calculation run. The calculation results are represented in a graph: annual operating hour vs heat load. The user by selecting other dataset can compare the result with existing calculations stored in database

4.4 Calculator for Relative Importance of Losses (RiL)

(*Evaluate DH Performance -> Calculator for Relative Importance of Losses (RiL)*)

This calculator obtains the coefficient of Relative Importance of Losses (RiL) by consumed heat, transferred heat to network and hours in a month. RIL represent the energy efficiency of a DH company and the sum of energy lost in DH (e.g. thermal loss through pipes, water replenishment, etc.) Also, this calculator takes into account the electricity needed to deliver power and heat to the consumers. The lower the RIL, the higher the energy efficiency of the DH company. The main users of this tool can be DH operators to have an overview about the energy efficiency of heat distribution processes or heat losses in the grid. This tool can also be used by municipalities and national stakeholders to evaluate the DH companies and write specific regulation acts to consequently give regulatory advices.

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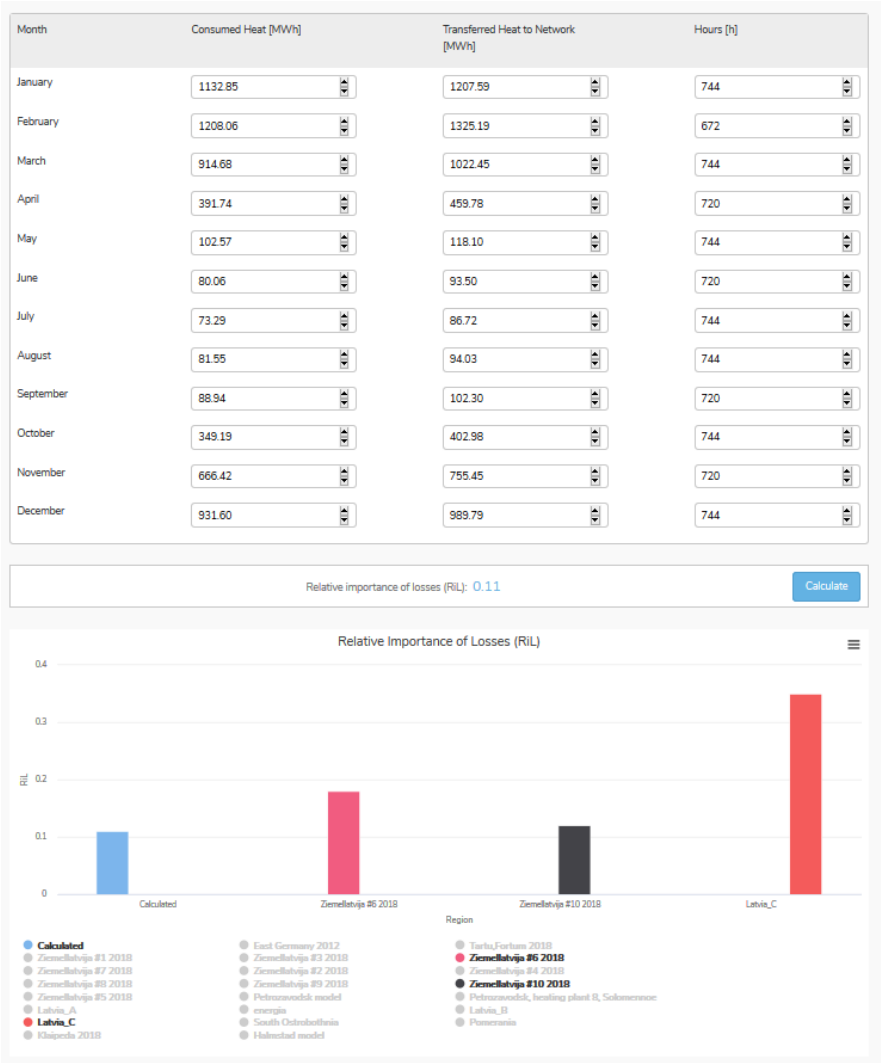

Month	Consumed Heat [MWh]	Transferred Heat to Network [MWh]	Hours [h]
January	1132.85	1207.59	744
February	1208.06	1325.19	672
March	914.68	1022.45	744
April	391.74	459.78	720
May	102.57	118.10	744
June	80.06	93.50	720
July	73.29	86.72	744
August	81.55	94.03	744
September	88.94	102.30	720
October	349.19	402.98	744
November	666.42	755.45	720
December	931.60	989.79	744

Relative importance of losses (RiL): 0.11 Calculate

Fig. 19 Calculator for Relative Importance of Losses (RiL)

To calculate the relative importance of losses (RiL) the following parameters should be indicated:

1. Consumed heat in a corresponding month
2. Transferred heat to network in a corresponding month
3. Hours in a corresponding month (number_of_days_in_a_month ×24)

All the input fields must be filled in to make the calculation run. The calculation result (RiL coefficient) is output at the bottom of the web page. The user by selecting other dataset can compare the result with existing calculations stored in database

4.5 Calculator for Primary Energy Factor (PEF)

(*Evaluate DH Performance -> Calculator for Primary Energy Factor (PEF)*)

The Primary energy factor (PEF) is an energy indicator used for quantifying the primary energy use of a plant. It is calculated by using the methodology described in the European Standard EN 15316-4-5.

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Using this calculator, the coefficient of the PEF is obtained by:

- Consumed heat
- Fuel input to the Heating Plant (HP) and Combined Heat and Power (CHP)
- Electricity production of the cogeneration plants
- Fuel
- Its primary resource factor (indicates how much primary energy is used to generate a unit of heat and electricity).

PEF shows heat and electricity production efficiencies and allows a comparison among different DH companies or different scenario. The lower the PEF, the higher the energy production efficiency of the DH company. The main users of this tool can be DH operators to have an overview about the energy efficiency of heat distribution processes or heat losses in the grid. This tool can also be used by municipalities and national stakeholders to evaluate the DH companies and write specific regulation acts to consequently give regulatory advices.

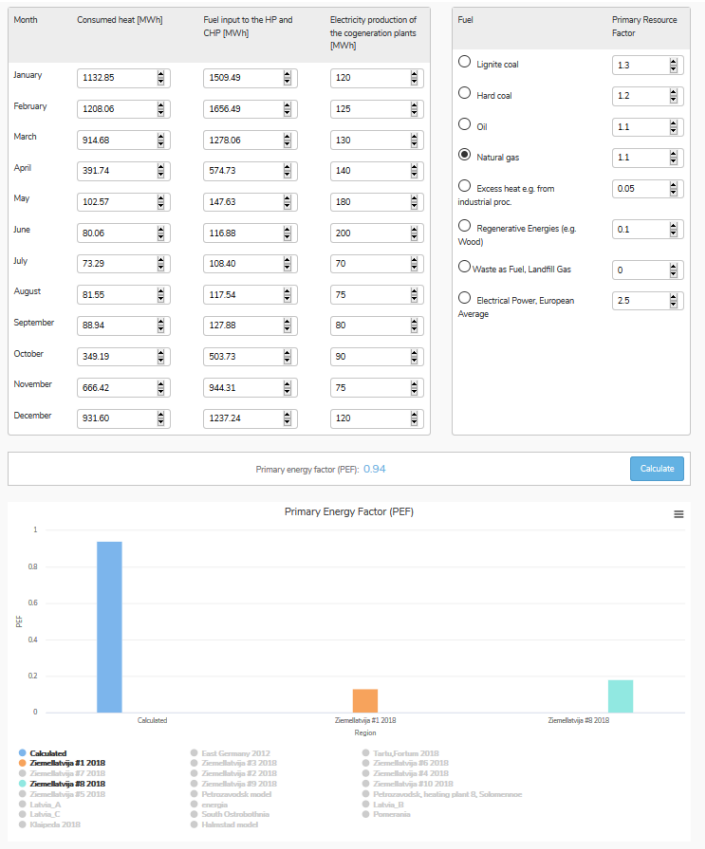

Fig. 20 Calculator for Primary Energy Factor (PEF)

To calculate the Primary Energy Factor (PEF) the following parameters should be indicated:

1. Consumed heat in a corresponding month
2. Fuel input to the HP and CHP
3. Electricity production of the cogeneration plants
4. Selected fuel and its Primary Resource Factor

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All the input fields must be filled in to make the calculation run. The calculation result (RiL coefficient) is output on a barchart and the user by selecting other dataset can compare the result with existing calculations stored in database

4.6 Using DH ranking and comparison tool

The DH ranking and comparison tool (*Evaluate DH Performance -> DH ranking and comparison tool*) (this tool can be accessed by public user) allows to compare and analyse the heat loads, RiLs and PEFs of different regions for the potential development of a LTDH strategy. In order to evaluate various DH systems and find the most suitable one for the development of a system, nine criteria are applied in the multi-criteria ranking tool:

- Specific fuel consumption
- Power to heat ratio
- Specific heat consumption for heating per m2
- RES share
- Legal regulation of Low-temperature DH
- Specific heat losses in network
- Specific CO_2 emissions
- Specific power consumption
- Affordability of DH heat

The ranking results show the efficiency of the performance of existing DH system cases in municipalities. Results are ranked from the smallest to the largest efficiency performance.

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EUROPEAN REGIONAL DEVELOPMENT FUND

Select Country: --- Select State: --- Select City: ---

All	Country/State/City	Model Name
☑	Germany	East Germany 2012
☑	Estonia / Tartumaa / Tartu linn	Tartu,Fortum 2018
☑	Latvia	Ziemellatvija #1 2018
☑	Latvia	Ziemellatvija #3 2018
☑	Latvia	Ziemellatvija #6 2018
☑	Latvia	Ziemellatvija #7 2018
☑	Latvia	Ziemellatvija #2 2018
☑	Latvia	Ziemellatvija #4 2018
☑	Latvia	Ziemellatvija #8 2018
☑	Latvia	Ziemellatvija #9 2018
☑	Latvia	Ziemellatvija #10 2018
☑	Latvia	Ziemellatvija #5 2018
☑	Russian / Respublika Kareliya / Prionezhskiy Rayon	Petrozavodsk model
☑	Russian / Respublika Kareliya / Prionezhskiy Rayon	Petrozavodsk, heating plant 8, Solomennoe
☑	Latvia	Latvia_A
☑	Denmark	energia
☑	Latvia	Latvia_B
☑	Latvia	Latvia_C
☑	Finland	South Ostrobothnia
☑	Poland / Wojewodztwo Pomorskie	Pomerania
☑	Lithuania / Klaipeda County / Klaipeda	Klaipeda 2018
☑	Sweden / Halland / Halmstads Kommun	Halmstad model

Evaluate

Fig. 21. DH ranking and comparison tool

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Fig. 22. DH ranking and comparison tool

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5 Moving towards low temperature DH section

Moving towards low temperature DH section is oriented to target groups related to municipalities, planers, politicians etc. where we can find information on financing schemes and business models and main steps for development of low temperature district heating strategy including algorithms references and useful links describing different tools for energy plans and strategies development.

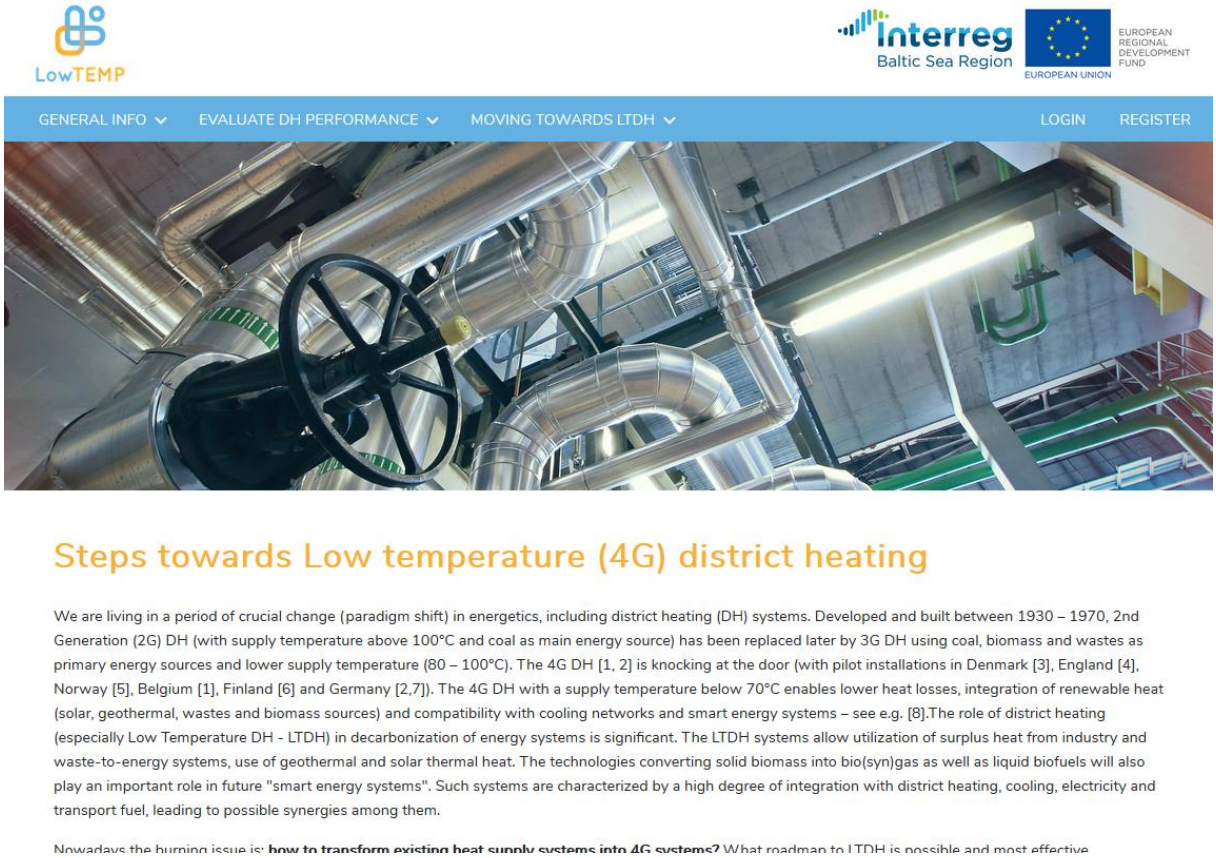

Fig. 23 Steps toward low temperature (4G) district heating