Best Practice No. 1

Implementation of LTDH in existing buildings and installations

LowTEMP training package - OVERVIEW

Introduction

- Intro Climate Protection Policy and Goals
- Intro Energy Supply Systems and LTDH
- Energy Supply Systems in Baltic Sea Region

Energy Strategies and Pilot Projects

- Methodology of Development of Energy Strategies
- Pilot Energy Strategies – Aims and Conditions
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- CO_2 emission calculation
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Financial Aspects

- Life cycle costs of LTDH projects
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Technical Aspects

- Pipe Systems
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- Thermal, Solar Ice and PCM Storages
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- LT and Floor heating
- Tap water production
- Ventilation Systems

Best Practice

- Best Practice I
- Best Practice II

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Motivation and Goal

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On the road to LTDH

- The main motivation and goal is to present various possible roads to low temperature (4 Gen) district heating implementations
- Here we concentrate on issue of possible LTDH implementation in an existing city districts (after building renovation and without it) and a whole city

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What is 4th Generation District Heating (DH)?

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- **1st Gen DH** - steam-based system fuelled by coal; first introduced in the US in the 1880s; became popular in some EU countries, too.
- **2nd Gen DH** (1930 – 1970) supply water temperature above 100°C and coal as main energy source
- **3rd Gen DH** (most popular now) lower supply temperature (80 – 100°C); use coal, biomass and wastes as primary energy sources;
- **4th Gen DH** knocking at the door (with pilot installations in Denmark, England, Norway, Belgium, Finland, and Germany)
  - supply temperature below 70°C (LTDH) enables lower heat losses,
  - integration of renewable heat (solar, geothermal, wastes and biomass sources)
  - compatibility with cooling networks and smart energy systems.
- **5th Gen DH** being discussed; integrates heating and cooling, enables demand side response and related thermal energy storage, and wider integration of waste/surplus heat sources. (e.g. Ectogrid™ E.ON Sverige AB)

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Low Temperature District Heating (4G LT DH)

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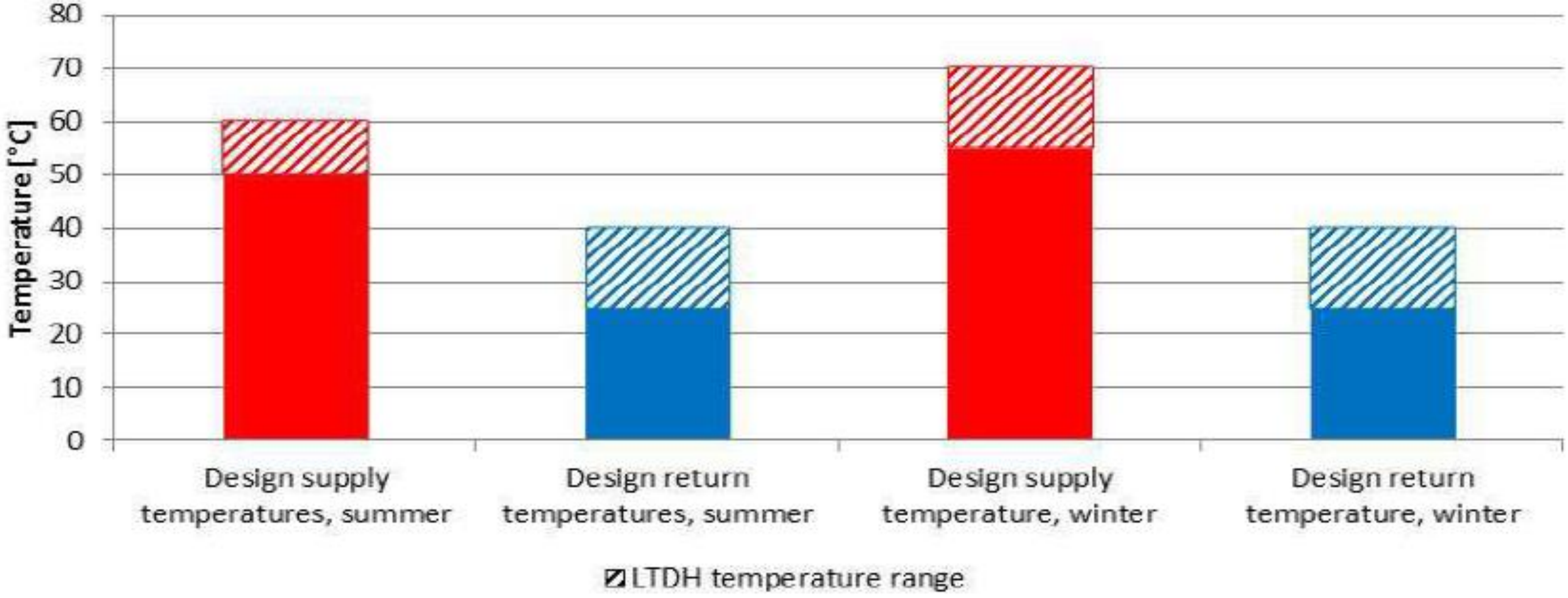
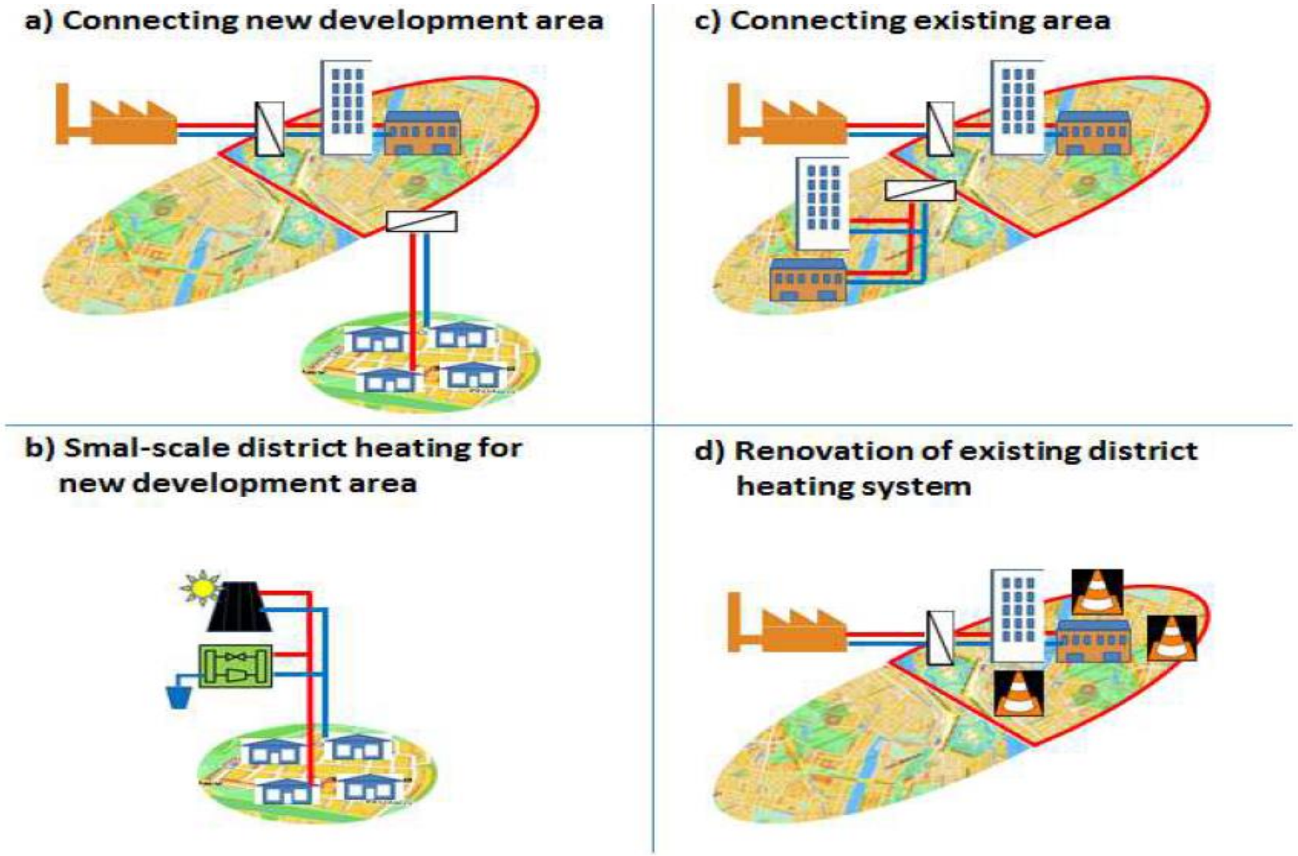
From 1 generation (above 100°C) to 4 generation (below 60°C) district heating

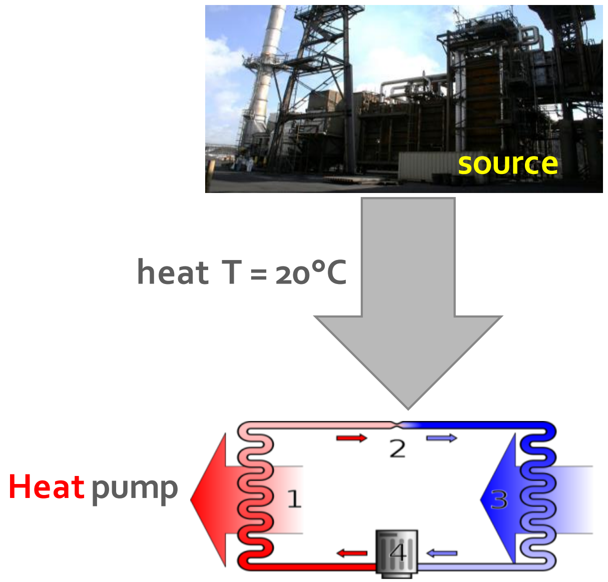


Source: P.K. Olsen et al. [1.1]

Roadmap to Low Temperature DH



e) Low temperature waste heat source to heat pump



f) Lowering temperaturę in whole DH

Source: P.K. Olsen et al. [1.1]

Content

- IMPLEMENTATION IN RENOVATED BUILDIGS
- Energy efficient renovation of buildings and implementation of LTDH, Albertslund (DK)
- Conversion of a school into a passive house, Max-Steenbeck-Gymnasium (GER)
- Comprehensive thermomodernization and implementation of LT heating system, Jabłoń (PL)
- IMPLEMENTATION IN unRENOVATED BUILDIGS
- Pilot LTDH system in existing detached houses, Sønderby (Høje-Taastrup, DK)
- IMPLEMENTATION IN A WHOLE CITY
- How to change the existing district heating network into LTDH grid – implementation of pilot project in Łomża (PL)

Testing LTDH in renovated buildings

1. Albertslund, Denmark

Energy efficient renovation of buildings and implementation of LTDH

Project profile

Topic	**Energy efficient renovation Implementation LTDH**
Year of construction	2015
Project leader	Albertslund Kommune

Albertslund, Denmark

Project background

- Albertslund is known as living-lab for new eco-solutions, including energy and finance saving heating system
- Heat is provided from 4 sources of the Copenhagen metropolitan district heating system (in Albertslund network area there is only one peak load boiler of few hundred kW power and no CHP system)
- In Copenhagen metropolitan area there are located:
  waste combusting boiler and CHP plant (393 MW),
  multi-fuel CHP plant (2651 MW, heat output from biomass of approx. 1500 MW), reserve/peak boiler; thermal storage capacity is 3000 MWh without the storage being built in Høje Taarstrup

Goal

By 2025 all heat and energy will be produced without CO_2 emission – by introduction of 4th generation DH and better use of local energy sources (wind farms and heat pumps)

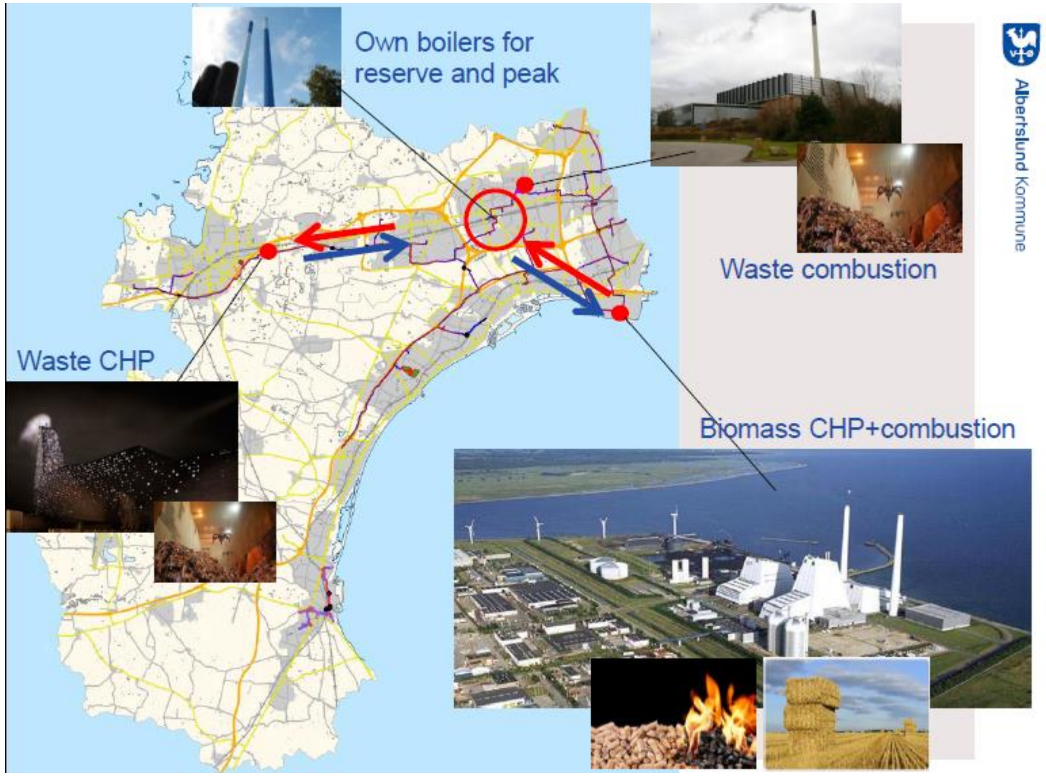


Figure 1: Location of heat sources in the Copenhagen metropolitan area.
Source: Albertslund Kommune, Housing department, Denmark

Albertslund, Denmark

Pilot project

- takes place in part of Albertslund: old and poor housing district
- 560 houses, built from 60's to 70's
- finished in 2015
- largest LTDH system in Denmark

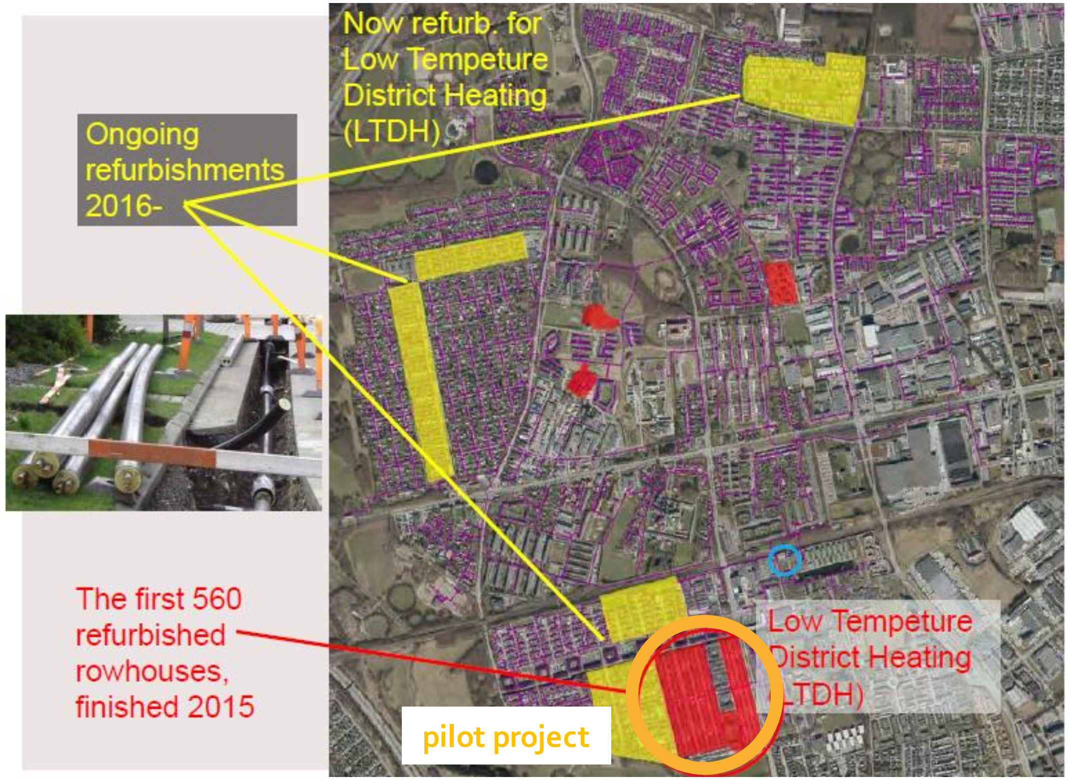


Figure 2: Location of the project in Albertslund.
Source: Albertslund Kommune, Housing department, Denmark

Albertslund, Denmark

Pilot project: Approach

- comprehensive refurbishment, which included: roof, wall and basement insulation, materials with a factor of λ = 0.020 W/(m*K) were used
- floor heating system with additional new radiator (two or three layer LT radiators) with blowers
- the supply temperature of the LTDH city system is 57 °C, e.i. at the inlet to the heat exchanger of every house

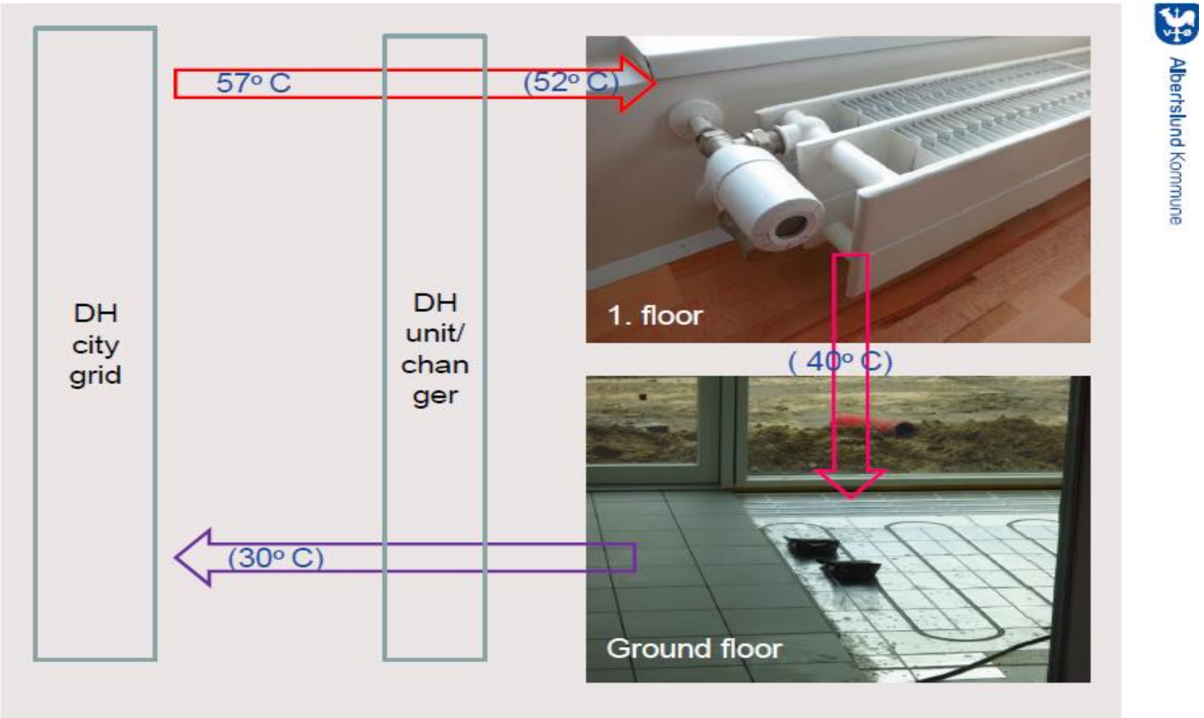


Figure 3: The radiator and ground floor installation.
Source: Albertslund Kommune, Housing department, Denmark

Albertslund, Denmark

Pilot project: Results

- embellished appearance of the quarter through refurbishment
- heat use and costs have decreased by 50%
- poor citizens can cover the renovation costs by saving on energy bills

Figure 4: Building facade before and after refurbishment.
Source: Albertslund Kommune, Housing department, Denmark

2. Max-Steenbeck-Gymnasium, Germany

Conversion of a school into a passive house

Project profile

Topic	**Reconstruction of school into passive house**
Year of construction	2010 - 2012
Project leader	City of Cottbus

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Max-Steenbeck-Gymnasium, Germany

Project background

- school was built in 1974 from prefabricated concrete slabs

Goal

conversion into passive house with best economic efficiency and consideration of operational costs for 30 years

Figure 1: Building facade. Source: Cornelia Siebke, BTU Cottbus-Senftenberg

opening

decision	planning		reconstruction		monitoring		optimization	
2008	2009	2010	2011	2012	2013	2014	2015	2016

Max-Steenbeck-Gymnasium, Germany

Pilot project: Approach

- use of ground heat storage (injection of heat from solar collectors)
- geothermal energy for winter and summer use (pre-heating and pre-cooling of the ventilation system)
- heating by use of the return flow from the radiators

Figure 2: The heat exchanger. Source: Jan Gerbitz, ZEBAU, Germany

Max-Steenbeck-Gymnasium, Germany

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Pilot project: Results

- reconstruction costs – EUR 12.8 million
- building construction – 460 EUR/m²
- building services (including tax) – 254 EUR/m²
- less than 34 kWh/m² annually for heating and mechanical ventilation
- about 55% of heat energy from return flow
- only 17% of heat consumption from DH after reconstruction

Benefits of return flow

- lower return flow temperature
- lower heat loss on the way back to the heating plant
- higher efficiency of heat transfer in the heating plant
- sustainable technology for low temperature heat sources

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3. Jabłoń, Poland

LT local heating system

as an element of comprehensive thermomodernization of buildings

Project profile

Topic	Comprehensive thermomodernization and implementation of LT heating system
Year of construction	2020
Project leader	Municipality of Jabłoń Housing Communities

Jabłoń, Poland

Project background

- Agricultural rural region
- Part of the Jabłoń village is under protection of the heritage conservator (including the park and palace complex - the former seat of the Zamoyski family) – building renovations had to take into account requirements of the conservator.
- Since 2006 solar PV modules have been installed at about 350 private and public buildings.

Goal

Improvement of energy efficiency in multi-family residential buildings of the commune through comprehensive thermomodernization using low-temperature energy sources.

Project "Renewable energy sources in the Municipality of Jabłoń " was co-financed from EU funds.

Figure 2: Field crops.
Source: J. Halicki, [3.2]

Figure 3: Palace in Jabłoń.
Source: A. Sikora-Terlecka, [3.3]

Figure 1: Location map of the Municipality of Jabłoń.
Source: OpenStreetMap contributors, [3.1]

Figure 4: Water reservoir in Jabłoń.
Source: Materials of the Municipality of Jabłoń, [3.4]

Figure 5: Solar installations in a single-family building in the commune.
Source: Materials of the Municipality of Jabłoń, [3.5]

Jabłoń, Poland

Project object – state before modernization

General characteristics

1	Type of buildings	multi-family residential buildings - terraced houses	
2	Construction year	1990	
3	Building technology	traditional - brick buildings (aerated concrete)	
4	Total building volume	[m³]	8 000
5	Total volume of the heated part	[m³]	3 540
6	Total usable area	[m²]	1 733
7	Total area of the heated part	[m²]	1 460
8	Number of terraced segments		4
9	Number of floors		2 + attic (partially usable)
10	Total number of inhabitants	[persons]	52
11	Total number of apartments	[pcs.]	22


Figure 6: General view of buildings before modernization. Source: T. Żurek - IMP PAN Gdansk

Heating system

Coal boiler

Storage heaters in a boiler room

Individual electric heaters

Figure 7: The heating system before modernization. Source: T. Żurek – IMP PAN Gdansk

1	Heat source	Coal boiler room (space heating + domestic hot water). HEITZ MAX EKO 150 boiler with a power of 60-150 kW. Year of assembly - 2010. Operated only during the heating season.
2	Preparation of domestic hot water	1) Central preparation for 17 residential premises Only during the heating season. Storage heaters (2x750 l) supplied from the boiler room. 2) Individual preparation - electric heaters 17 apartments - only summer period. 5 apartments - all year round.

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Jabłoń, Poland

Basic assumptions of the project

Improving the thermal insulation of building partitions

Heat transfer coefficient

1. Insulation of building partitions

1. Exterior walls of basements → U = 0,20
2. External walls of overground storeys → U = 0,19÷0,22
3. Floor above the unheated basement → U = 0,25
4. Ceilings under the unused attic → U = 0,14
5. Internal walls between heated and unheated rooms (basement and attic) → U = 0,20÷0,22

2. Installation of new windows and doors

1. Windows in residential premises → U = 0,90
2. Windows and external doors in common areas → U = 0,90 / 1,30
3. Interior doors in partitions separating heated and unheated rooms → U = 1,30

3. Additional improvements

New moisture insulation basement walls in contact with the ground

Thermal insulation of external walls.

Thermal insulation of the ceiling above the basement and attic partitions

Insulation of basement walls

Figure 8:
Thermomodernization works in community buildings.
Source: T. Żurek – IMP Gdansk

Jabłoń, Poland

Figure 9:
Heat pumps and buffer tank installed in the buildings.
Source: T. Żurek – IMP Gdansk

Basic assumptions of the project

Modernization of the heating system

1. Modernization of the building's thermal energy supply system

1. Liquidation of the existing coal-fired boiler room
2. The use of low-temperature heat sources designed to work for the needs of heating and hot water preparation (2 heat pumps with a thermal power of 42.8 kW each)
3. Installation of photovoltaic cells for electricity production for own needs (electricity supply to heat pumps) 66 pcs of PV panels x 300 W - total power 19.8 kW.
4. Installation of an energy management system in the building.

2. Modernization of the central heating installation

Replacement of the entire central heating installation in building segments for a new one (a low temperature installation - heating water parameters 55 / 45 °C).

3. Modernization of the hot water supply system

1. Liquidation of individual sources of domestic hot water preparation
2. Coverage of all apartments with central year-round hot water supply
3. Modernization of the existing hot water installation in the buildings (thermostatic valves on hot water circulation, new thermal insulation of pipelines).

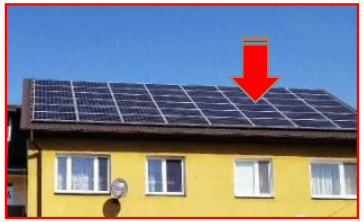

Figure 10:
Photovoltaic installation in the south-eastern part of the building.
Source: T. Żurek – IMP Gdansk

Figure 11:
Installation of low-temperature heating in apartments.
Source: T. Żurek – IMP Gdansk

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Jabłoń, Poland

Pilot project: Expected results

Energy and ecological effects

No.	Name	Unit	Before modernization	After modernization	Effects (decrease) [%]
1	Usable energy demand	GJ/year	811	432	47
		MWh/year	225,2	120,1	
2	Final energy demand	GJ/year	1 520	161	89
		MWh/year	422,3	44,7	
3	Primary energy demand	MWh/year	496,7	61,7	88
4	Unit indicators				
	a) usable energy	kWh/(m² year)	154	82	47
	b) final energy	kWh/(m² year)	289	31	89
	c) primary energy	kWh/(m² year)	340	42	88
5	CO_2 emissions	tons of CO_2	154	19	88
6	Electricity production in the PV installation			20	MWh/year
7	Covering the demand for electricity for heat pumps by a PV system			45	%
8	Share of RES in covering the demand for heat			83	%

Table 1: Expected energy and ecological effects.
Source: T. Żurek - on the basis of the energy audit [3.6]

Figure 12: Views of the buildings after modernization. Source: T. Żurek – IMP Gdansk

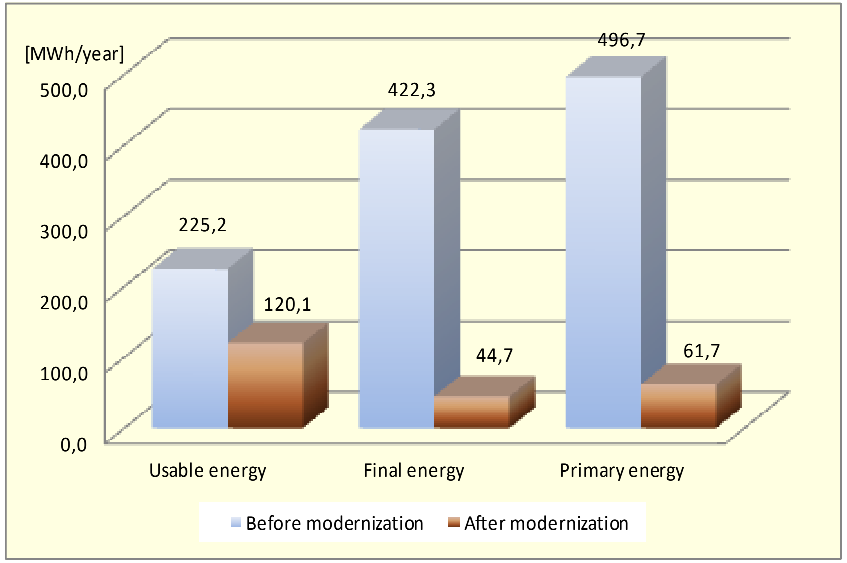

Figure 13: Comparison of energy needs of buildings before and after modernization.
Source: T. Żurek – IMP Gdansk

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Pilot project: Expected results

Economic effects

No.	Name Name	Unit	Before modernization	After modernization	Effects (decrease or increase) [%]	
1	Energy costs (heating + hot water)	EUR / year	15 378	3 719	↓ decrease	76
2	Unit costs of heat energy	EUR / GJ	10,11	23,12	↑ increase	129
		EUR / m^2	10,53	2,55	↓ decrease	76

Table 2: Expected economic effects. Source: T. Żurek - on the basis of the energy audit [3.6]

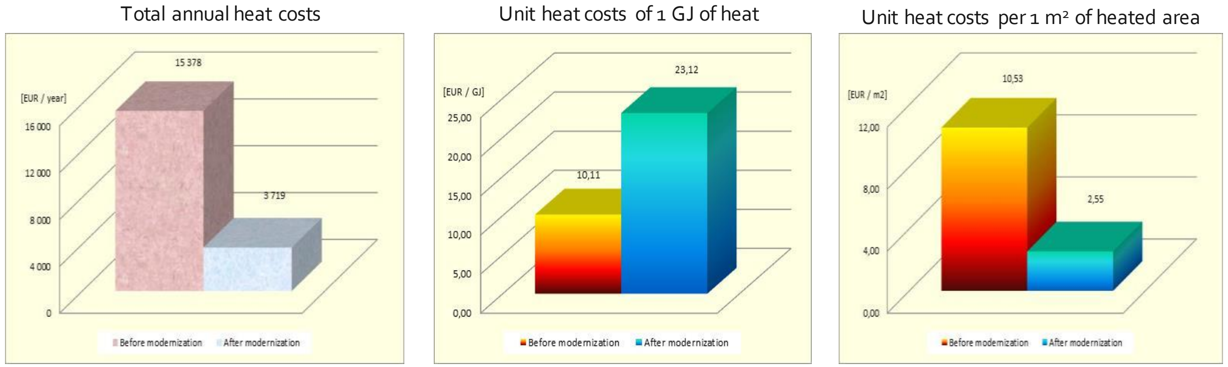

Figure 14: Comparison of economic indicators before and after modernization. Source: T. Żurek – IMP Gdansk

Financial characteristics

No.	Name	Units	Value
1	Total investment costs	PLN	1 615 000
		EUR	354 945
2	Unit investment costs per 1 m^2 of usable floor space of the buildings	PLN / m^2	932
		EUR / m^2	205
3	Simple period back time SPBT		
	a) including the full investment costs	years	30,4
	b) after taking into account EU funding	years	4,6

Table 3: Financial characteristics. Source: T. Żurek – IMP PAN Gdansk

85% funding obtained

Jabłoń, Poland

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Conclusions

1. The efficiency and economy effects of the heat suply by low-temperature heat pumps depends a lot on the amount of electricity produced on site (PV modules).
2. In the considered case, necessity to take into account the requirements of conservator, excluded the installation of PV panels on the roof surface from the side of the historic palace and park complex. This resulted in a limited number of PV panels and reduced production of own electricity (covering only 45% of the heat pumps' demand). This has an impact on the unit costs of 1 GJ of heat energy, which increased if compared to the state before modernization.
3. The increase in unit costs of 1 GJ of thermal energy is compensated by very large savings of the final energy used in the buildings (decrease in consumption by 89%), which means that the total costs of heating and domestic hot water preparation are 76% lower than before the modernization.
4. The project is therefore characterized by very large economic benefits for residents resulting from significantly reduced fees that will be incurred for heating and hot water preparation.

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Testing LTDH in unrenovated buildings

4. Sønderby, Denmark

Pilot LTDH system in existing detached houses

Project profile

Topic	**Pilot LTDH system for detached houses**
Year of construction	2013
Project leader	Høje-Taastrup Fjernvarme a.m.b.a.

Sønderby, Denmark

Project background

- Høje-Taastrup municipality is a suburb of Copenhagen
- known for its green transformation agenda
- municipality consists of small residential areas, with family houses, row houses and some multifamily houses, most build in 60's to 80's

Goal

100% carbon free region by 2050

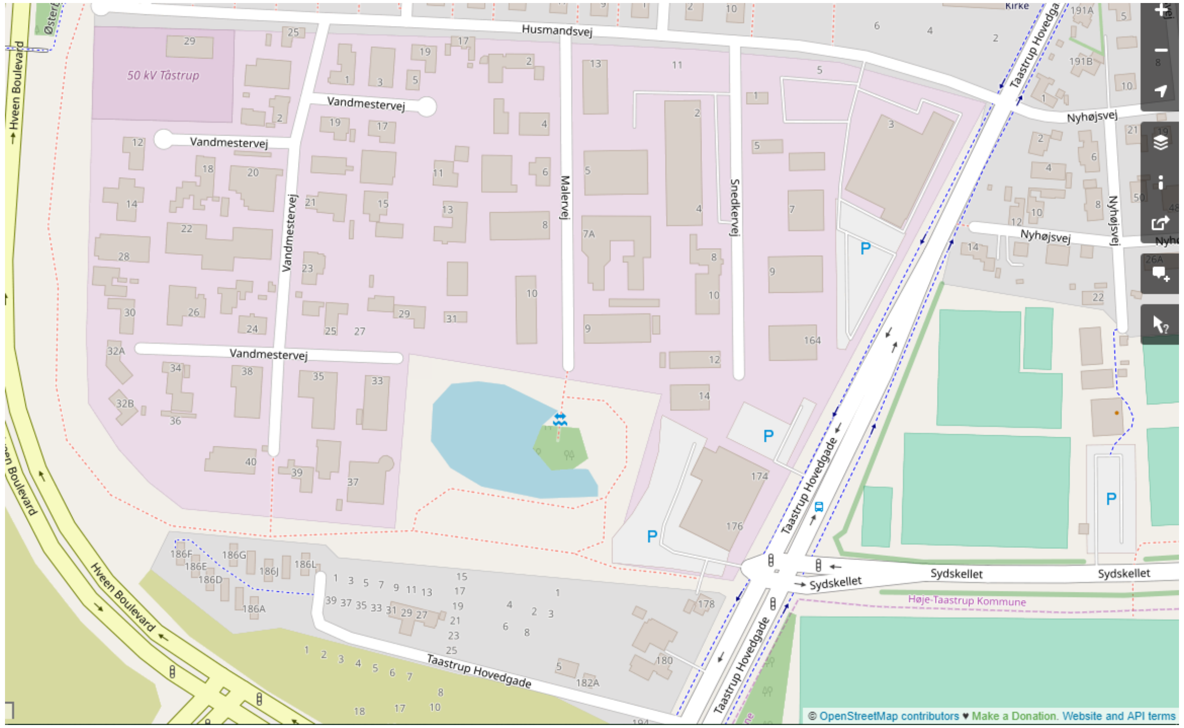

Figure 1: Location of the project in Høje-Taastrup. Source: OpenStreetMap contributors

Sønderby, Denmark

Pilot project

- development of a pilot LTDH system in 75 existing detached houses
- total heated area of 11,230 m^2
- old distribution pipelines – pair of plastic single pipes – account for heat losses of about 38-44% of the heat delivered from the central heat exchanger

Figure 2: Exemplary building in Høje-Taastrup. Source: Høje-Taastrup Fjernvarme a.m.b.a., Denmark

Sønderby, Denmark

Pilot project: Approach

- under-floor heating and return water flow from the neighbour area as the main supply ('cold supply') for the system
  - return water temperature can be mixed with a portion of hot water from the normal hot water utility supply if it is not sufficient for LTDH-network
- The 'cold supply' provides heat in the range of 30-67 °C (average 48 °C)
- The 'hot supply' provides heat in the range of 65-107 °C (average 80 °C)
- new pipe system: TwinPipe system, series 2, size 76 and smaller with Logstors alarm-system X4
  - ensures accurate identification of the failure location
  - heat conductivity factor λ = 0.022 W/(m*K)
- Installation of new substations in each house, an instantaneous water heater type, designed for a capacity of 32.3 kW

Sønderby, Denmark

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Pilot project: Results

- heat losses decreased to 13%
- measured supply and return temperature of LTDH network was 55 °C and 40 °C (design values 55 °C and 27-30 °C)
- at consumer substations, the temperatures were ~53 °C and 38 °C (design values 50 °C and 25 °C)
- LTDH is sensitive to consumer habits, e.g. large consumptions
- The application of LTDH is possible in existing housing areas

Year		Design	2012 (meas.)	1 Jan 2012 – 30 Jun 2013 (meas.)
Total heat delivered to LTDH network	MWh	-	1227.7	1978.6
Heat demand	MWh	-	1051.8	1715.1
Distribution heat loss	MWh	-	175.9	263.5
Distribution heat loss	%	15.0	14.3	13.3
Heat power, yearly avg.	kW	-	139.6	151.2
Supply temperature, DH	°C	-	77.7	79.9
Supply temperature, LTDH network*	°C	55-52	55.0	55.1
Return temperature LTDH network*	°C	27-30	40.3	40.1
Supply temperature, consumer substation	°C	Approx. 50	53.0	53.2
Return temperature, consumer substation	°C	Approx. 25	37.9	37.9
Electricity use, pumping station	kWh	-	22,169	36,505

* At the central shunt and pumping station

Table 1: Energy data for the project. Source: PK. Olsen [1.1]

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Implementation of LTDH in the whole city

5. How to change the existing district heating network into LTDH grid – implementation of pilot project in Łomża (PL)

Application of verified computer simulations method related to conversion the existing DHs into LTDHs, (ExToLTDHS$_{md}$)

Project profile

Topic	**Conversion of the whole existing DH into LTDH**
Year of construction	2017 - 2022
Project leader	Mieczysław Dzierzgowski WUT, IMP PAN

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Łomża, Poland

Project background

- **Łomża** is situated in the North – East Region of Poland, **63 000** inhabitants, **32.7** km²

Goal

- By 2022 : to convert the whole existing DH in to LTDH
  - From 121 / 65°C in 2017 to 89 / 48 °C in 2022
- Decreased heat production from coal
  - from 100% in 2017 to 11.6% in 2022

Figure. 1. Łomża City - view from the Narew River. Source: M. Dzierzgowski, IMP PAN, WUT

Figure. 2. On the Narew River. Source: M. Dzierzgowski, IMP PAN WUT

Łomża, Poland

Pilot Project 2017/2018 : On the road from existing DH to LTDH

- Nominal supply and return temperatures: **Ts/Tr = 121 ^{0}C / 65 ^{0}C**
- Nominal heat demand of the existing coal-fired heat plant with **boilers 98.52 MWt.**
- Verified heat demand: **73.71 MWt**
- **860** substations,
- **160 km** length of the DH grid
- Actual **heat losses** of DH grid: **- 12.5%**
- Primary energy source **– 100% coal.**

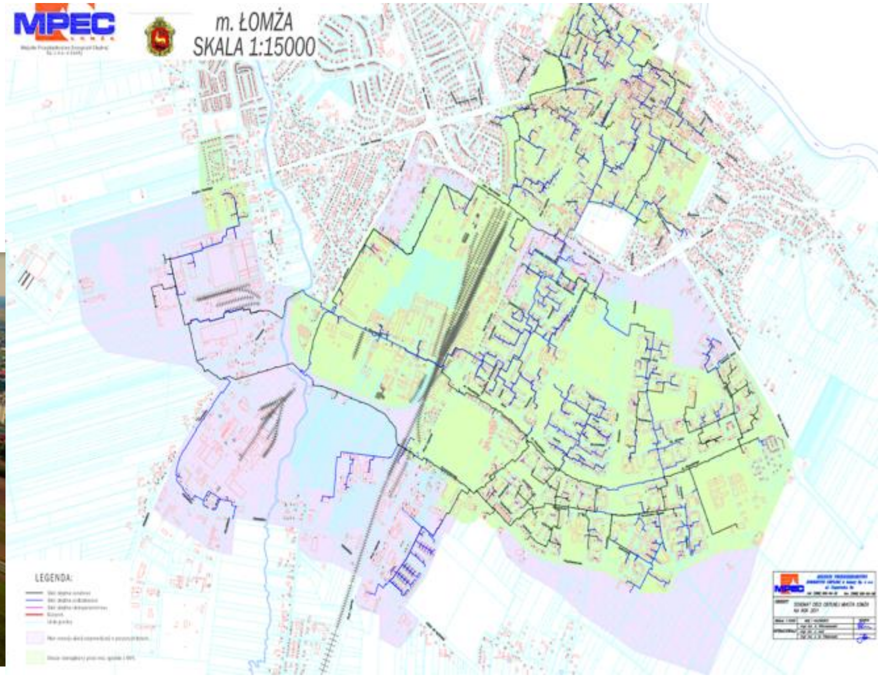

Figure 3. Layout of DHS in Łomża. Source: M. Dzierzgowski [5.1].

In 2017/2018 Seasonal Heat Production:

484 300 GJ, 100% from coal

Łomża, Poland

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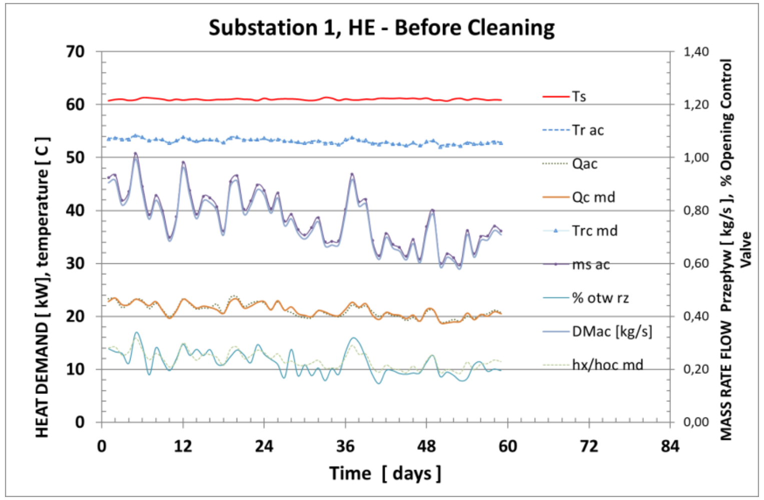
Project step 1 – 2017/2018

- data collection
- modeling of existing DH and verification of DH model
- analyses and elimination of failures and operation errors in the substations

Actual results

- Regulation of existing substations to comply with requirements of energy efficient LTDH
- Results: decreased (required) mass flow 55%; increased temperature drop – 43.2%
- Differences between Calculated an Actual Operational Parameters below 3.0%



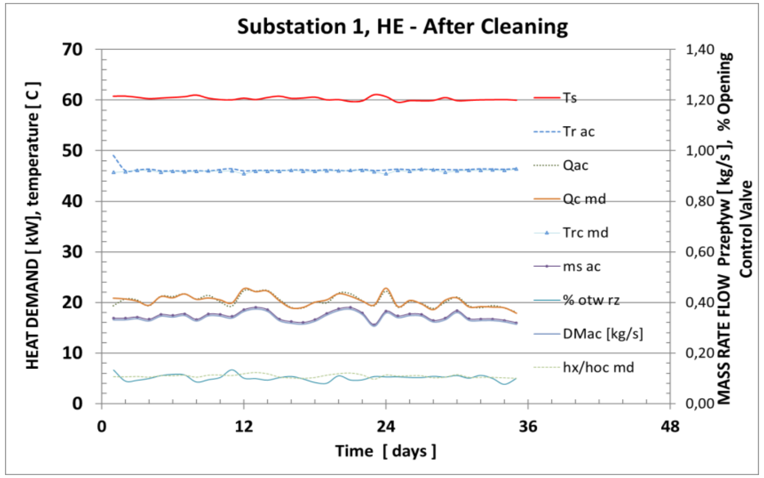


Figure 4. Substation 1 -measured and calculated hourly changes of the **heat demand, mass flow, supply and return temperatures**, % opening of the control valve - before and after **HEs cleaning**
Source: M. Dzierzgowski [5.1].

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Łomża, Poland

Project step 1 – 2017/2018

Substation 1

- Layout and measuring setup

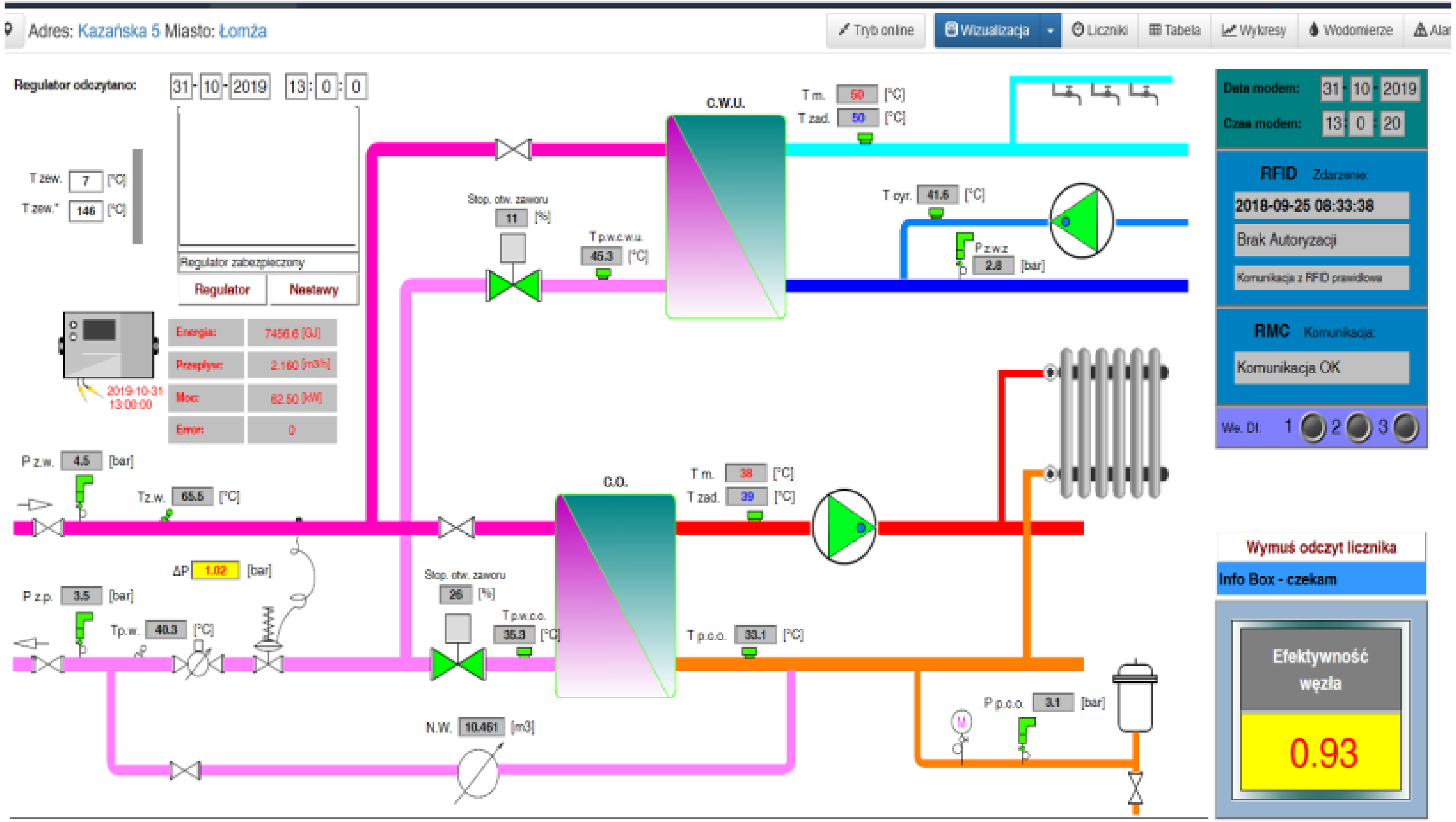


Figure 5. Substation 1 – Schematic Layout. Source: : M. Dzierzgowski [5.1].

Łomża, Poland

Project step 2 – 2017/2018

- computer simulations of the whole existing DH grid with the „New Individual Quantity/Quality Regulations"

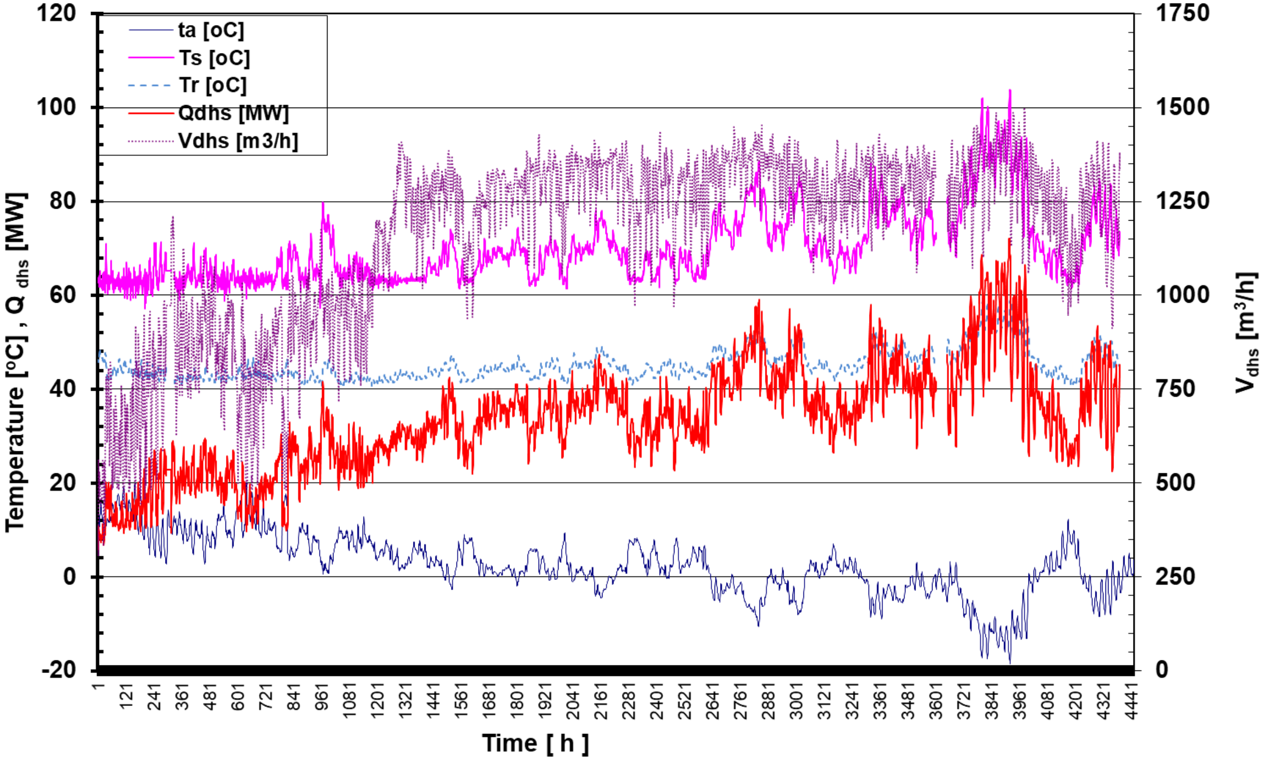


Figure 6.Time evolution of supply and return temperatures, flow rate and heat demand in 2017/2018 season, Source: M. Dzierzgowski [5.1]

Łomża, Poland

Project step 2 – 2017/2018

Actual results

- Decrease Nominal Supply Temperature **from 121.5 to 109.8 °C**
- decrease of seasonal DH heat losses **from 12.6 to 10.6%**
- Average seasonal DH return temperature: **Tr = 45.1 °C**
- Comparison between measured and calculated values of heat demand, mass flow and return temperature during heating season 2017/2018 – differences < 3%

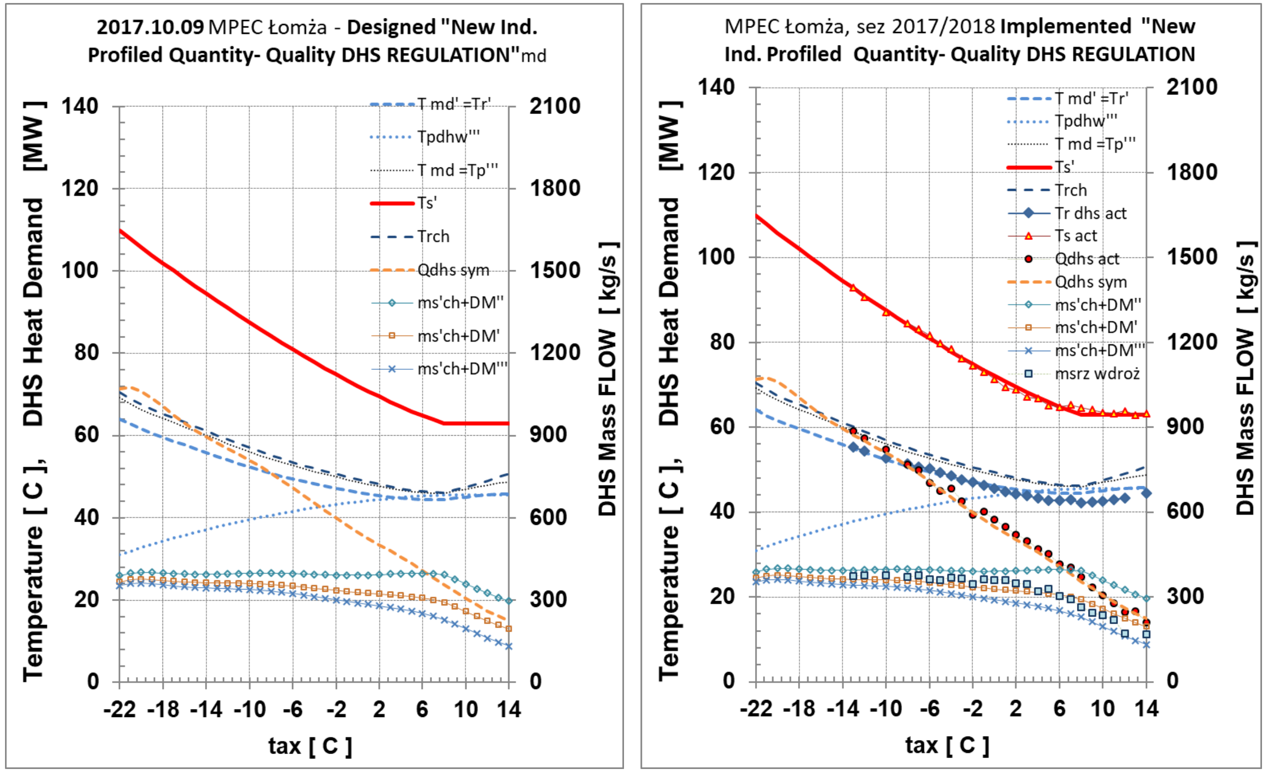


Figure 7. Measured and calculated supply and return temperatures, flow rate and heat demand of the whole DH grid - heating season 2017/2018. Source: M.Dzierzgowski [5.1]

Łomża, Poland

Project step 3 – 2019/2020

- Implementation of new biomass-fueled boiler and new gas-fired heat plant
- **New biomass-fuelled boiler 15 MW** was installed in the beginning of 2020
- **New gas-fired heat plant** implemented 2020. (In the remote region of existing DH grid with mostly old, refurbished buildings, year of construction **from 60's to 80's**)
- **New BIOMAS COGENERATION UNIT 14.0 MWt of heat and 2.8 MWe of power** is planned to be installed **in 2022.**

Goal : In 2020/2021 Seasonal Heat Production: 52.0% Biomas, 36.4% Gas, 11.6% Coal

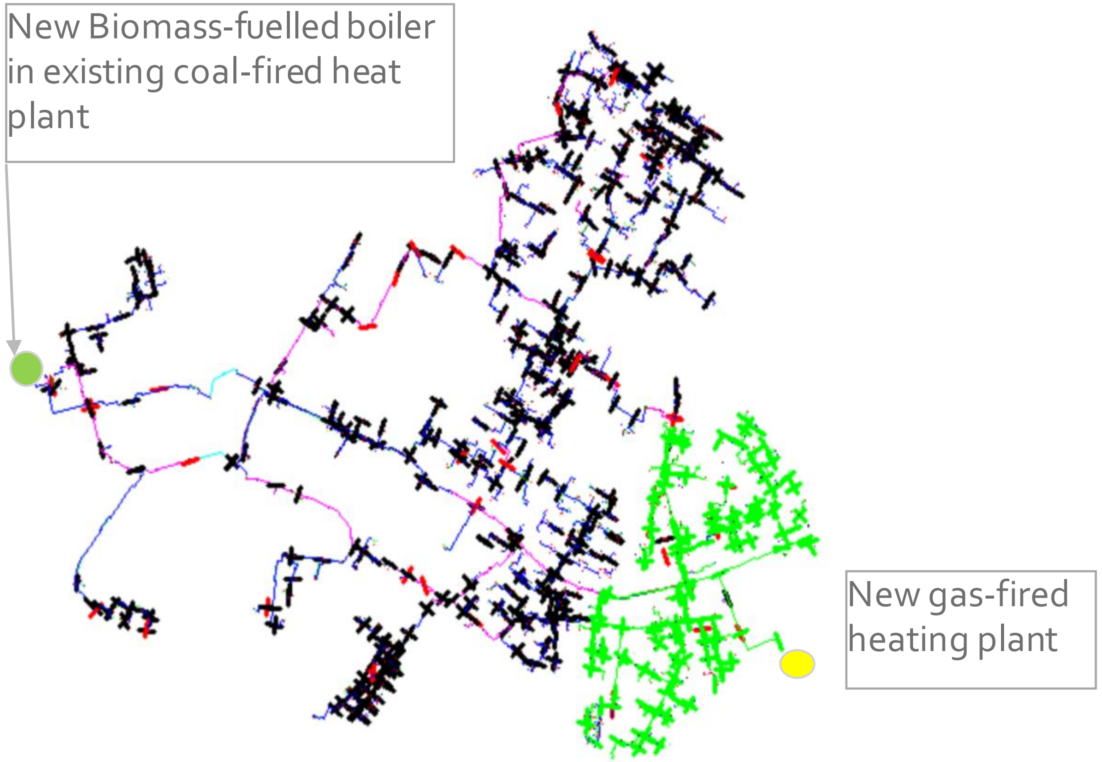
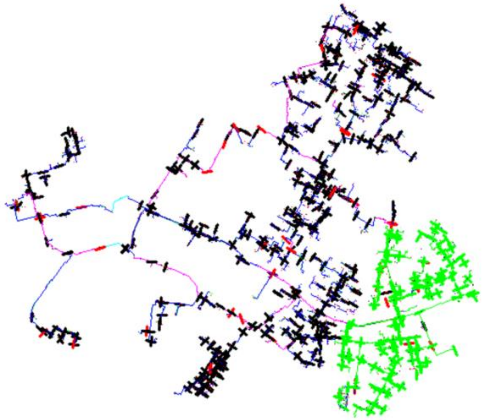


Figure 8. Layout of existing DH grid in Łomża - supplied from existing heating plant and new gas-fired heating plant (in yellow). Source: M. Dzierzgowski [5.1]

Łomża, Poland

Project step 4 – 2019/2020

- computer simulations
- optimization of seasonal regulation conditions of the new biomass boiler
- new gas-fired heat plant and common open DH network



DH Layout

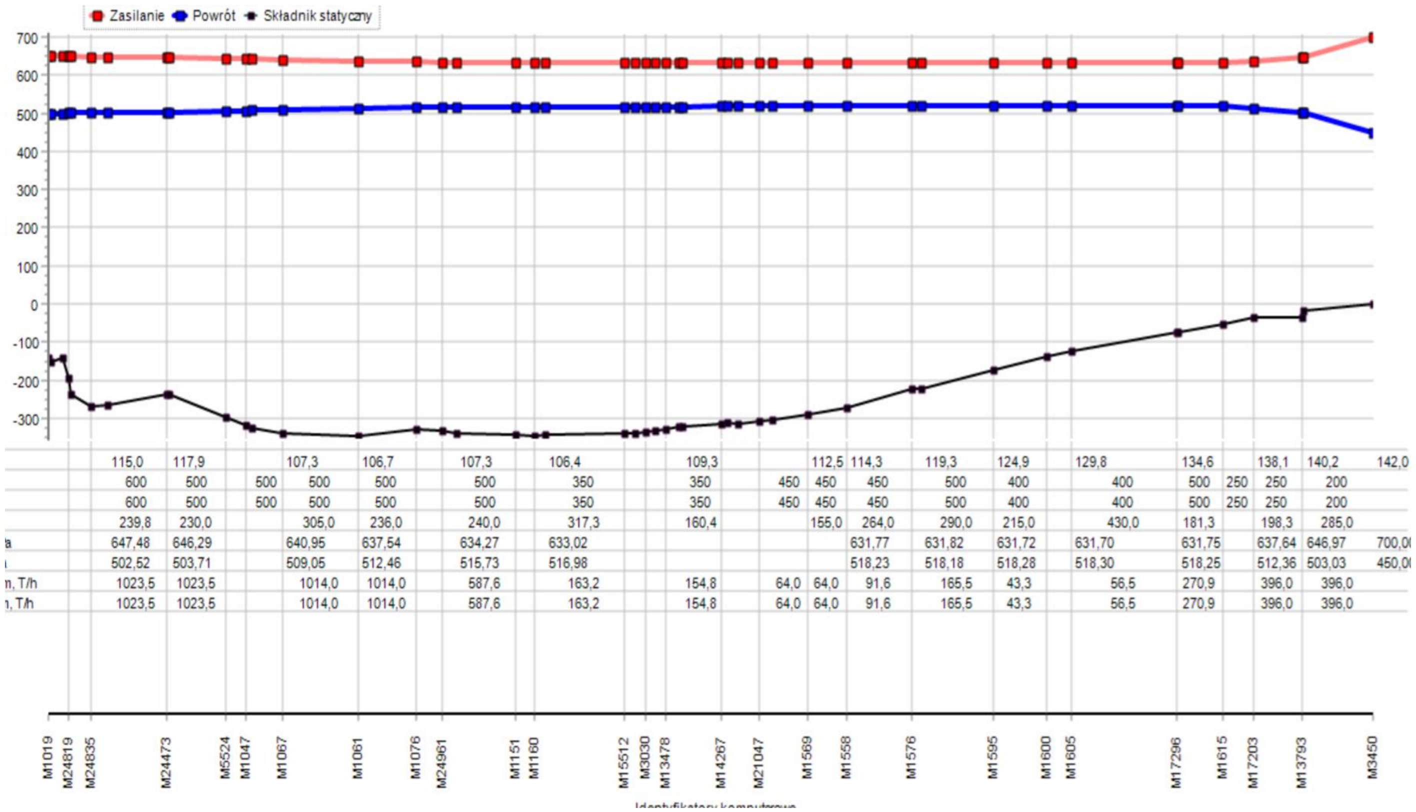


Figure 9. Preasure changes along network from coal/biomas fuelled boiler and DH Layout to gas-fired heat plant. Source: M. Dzierzgowski [5.1]

Łomża, Poland

Actual results

- **Decreased nominal supply temperature** in gas-fired heat plant and existing DH subsystem (17.5 MW) from **109.8 to 96.3 °C** (LTDH)
- Change of primary energy source – reduction of coal from 100.0% to 11.6%

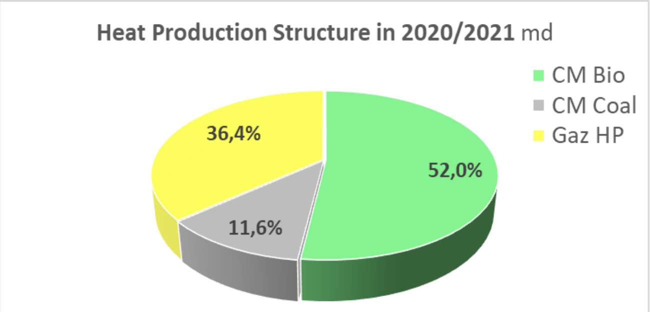


Figure 11. Primary energy sources during 2020/2021 season, Source: M. Dzierzgowski [6.1]

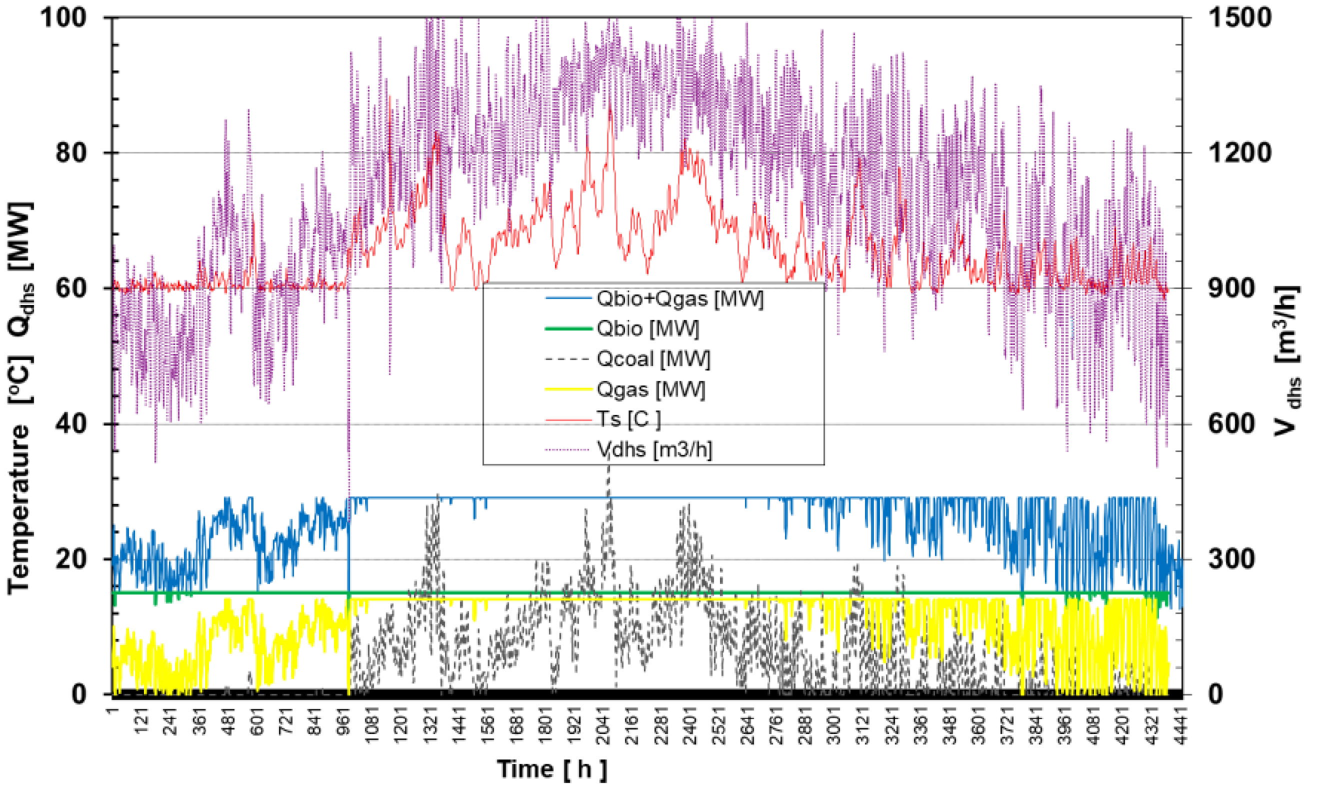


Figure 10. Calculated hourly changes of supply temperature, flow rate and heat load of gas, biomass and coal-fired boilers under 2019/2020 heating season conditions. source: [5.1] M. Dzierzgowski

Łomża, Poland

Goal by 2022

- Heat and energy will be produced with **75%** reduction of CO_2 emission
- Transformation of the whole existing DH into LTDH
- Decrease of DH heat losses from 12.6% to 9.5% (use of biomass - local energy source in boilers and CHP unit)

Source:: M. Dzierzgowski: IMP PAN, WUT

Conclusions

- The **verified model of the existing DH network in Łomża** based on thermal and hydraulic characteristics of the often oversized heat exchangers and radiators enables implementation of the „New individually profiled quantity/ quality seasonal regulation" **as well as transformation of DH into effective LTDH grids in all BSR countries before 2030.**
  - **Guidelines and demonstration** of how the WHOLE existing DH System should be prepared and transform to the LTDH **are available** but should be developed further.
- **LTDH networks are very sensitive** to characteristics and technical state-of-art of consumers space-heating installations (e.g. „Proper individually profiled heating curve", technical state of the heat exchangers their oversizing as well as quality and operational conditions of the control system)
- Transformation of the existing DH to LTDH grids is possible; leading to 15 - 25% reduction of the heat losses and emissions. The aim can be achieved after good verified pilot-project.

8. Conclusions

Conclusions

- Energy efficient refurbishment of all buildings in BSR countries from 2030 to 2050 is not feasible.
  - Guidelines and demonstrations of how buildings should be minimally prepared for LTDH implementation are needed.
- LTDHs networks are very sensitive to characteristics and technical state-of-art of consumers space-heating installations as well as consumer habits (e.g. too large heat consumption) and counter measures should be proposed.
- High quality installation and operational control system are important for successful implementation of LTDH and comfort of citizens.
- Good operational data and user experiences are necessary for a well running project.
- Transformation of the existing DH to LTDH grids is possible; leading to 15 - 25% reduction of the heat losses and emissions.

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

9. References

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