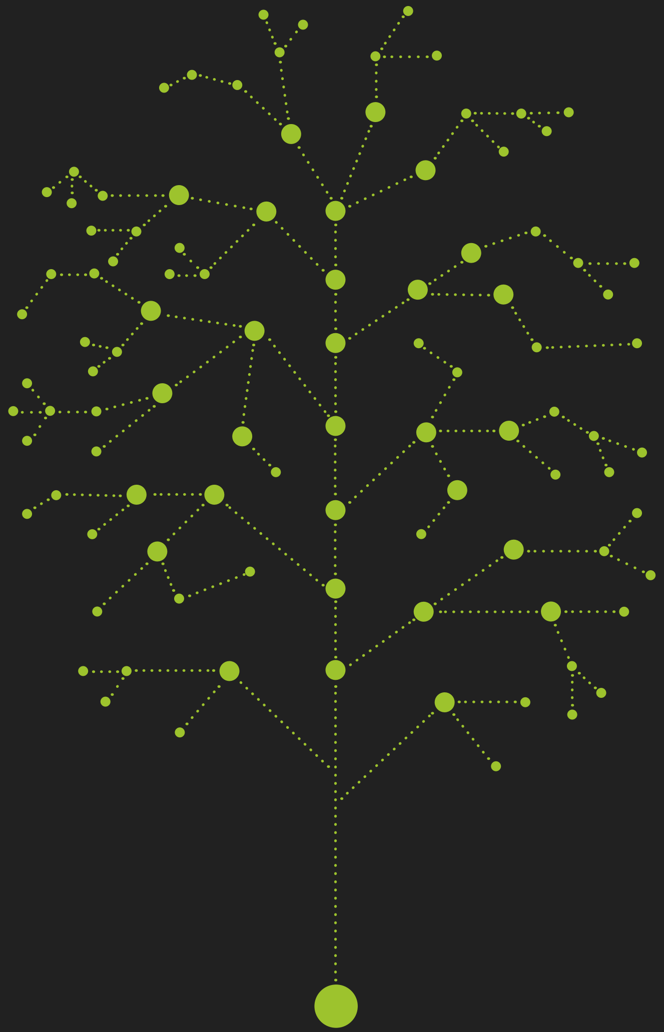


Cracow University
of Technology

environmental engineering

Municipal Infrastructure

Jarosław Müller

Kraków 2020

environmental engineering

Municipal Infrastructure

Jarosław Müller

Kraków 2020

CHAIRMAN OF THE CRACOW UNIVERSITY OF TECHNOLOGY PRESS EDITORIAL BOARD
Tadeusz Tatara

CHAIRMAN OF THE DIDACTIC BOARD
Elżbieta Węcławowicz-Bilska

SERIES EDITOR
Barbara Dąbrowska

REVIEWER
Marian Jan Hopkowicz

PROJECT COORDINATORS
Otmar Vogt
Janusz Pobożniak

PUBLISHING EDITOR AND PROOFREADING
Agnieszka Filosek

LANGUAGE VERIFICATION
LINGUA LAB s.c.

TYPESETTING
Anna Basista

COVER DESIGN
Karolina Szafran

This text was published as a part of the project ‘Excellence programming – PK XXI 2.0 Cracow University of Technology Development Program for the years 2018–2022’.

Funding from EU: 18,048,774.96 PLN

eISBN 978-83-66531-25-3
Online edition
12 publisher’s sheets

Wydawnictwo PK, ul. Skarżyńskiego 1, 31-866 Kraków; 12 628 37 25, fax 12 628 37 60
wydawnictwo@pk.edu.pl
www.wydawnictwo.pk.edu.pl
Correspondence address: ul. Warszawska 24, 31-155 Kraków

European Funds
Knowledge Education Development
Republic of Poland
European Union
European Social Fund

Table of Contents

Part 1

Gas networks

Fuel

High-methane natural gas
E (GZ50) from Carpatia and Russia
(> 90% CH_4)
Nitrogen-rich natural gas
L_s (GZ35) and L_w (GZ41.5)
From Greater Poland
(35–84% CH_4)

Fuel – properties

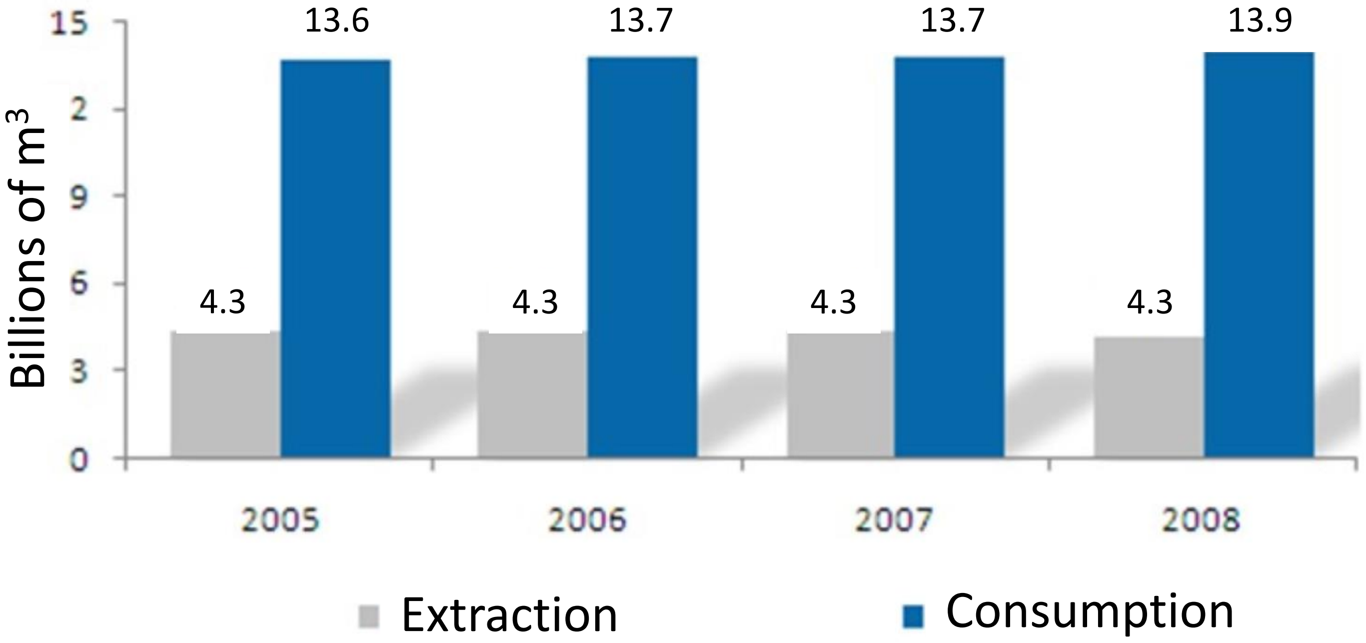
Methane density: 0.7 kg/m^3 Lighter than the air

The calorific value: 36 MJ/m^3

Explosive in mixture with air with 5–16% participation

It can be liquefied and transported under pressure as LNG (Liquified Natural Gas)

Extraction and consumption of natural gas in Poland



Gas pumping stations on the Yamal pipeline in Poland

LPG – Liquified Petroleum Gas

LPG – Liquified Petroleum Gas

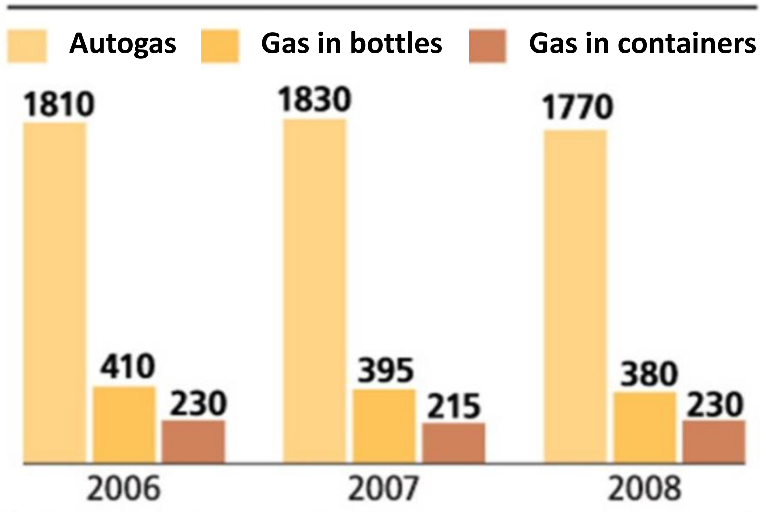
Propane (24–29%) + Butane (66–72%)

Gas density: 2.0 + 2.7 kg/m^3 – heavier than air

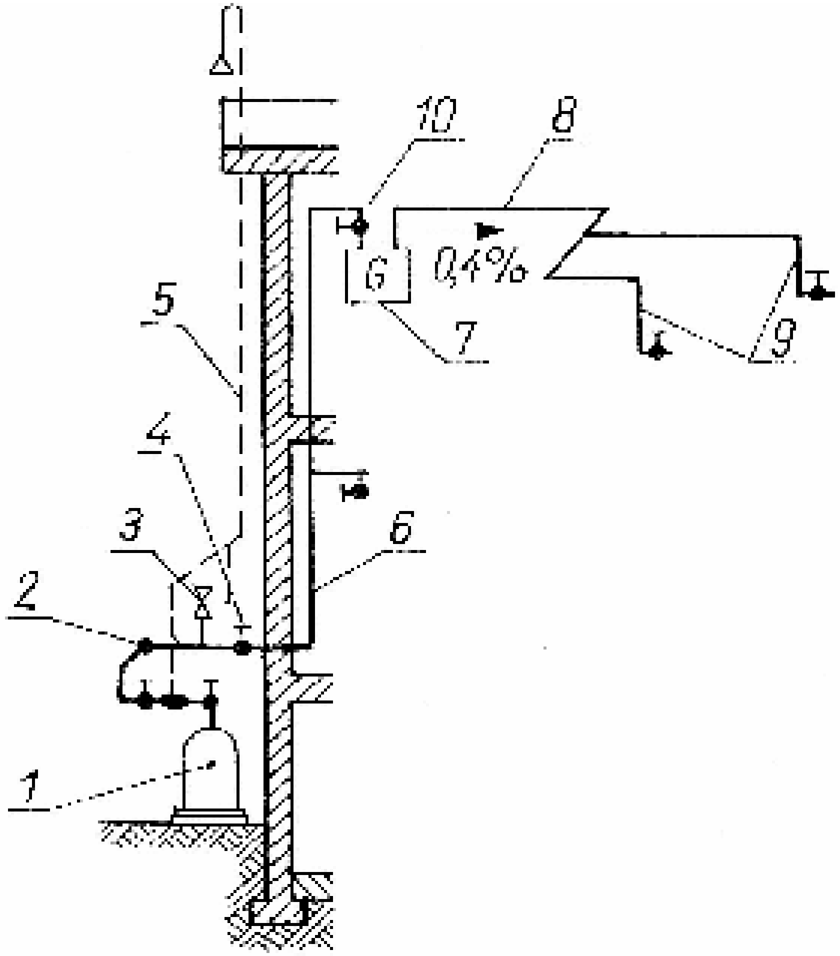
Liquid density: 0.53–0.60 kg/dm^3

The calorific value 12.8 kWh/kg
(94 MJ/m^3)

LPG – sales structure
[thousands of tons]



Cylinder installation



Cylinder installation

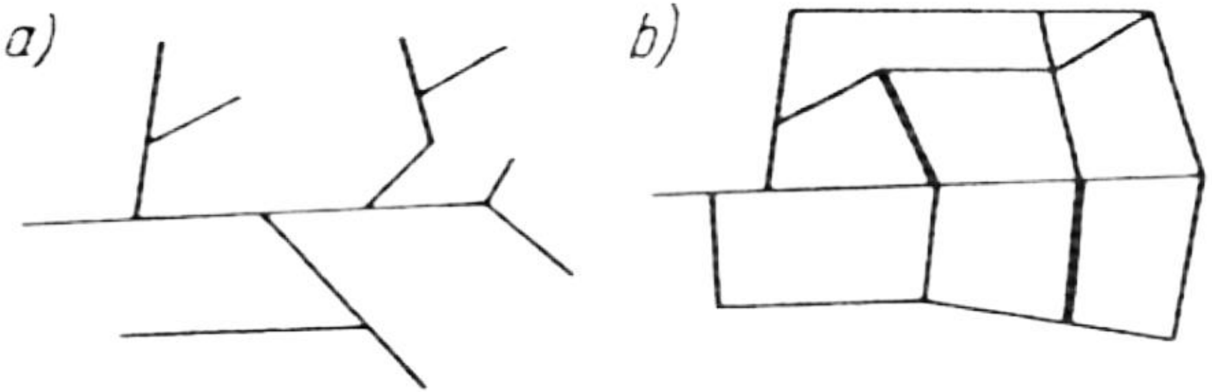
Operation

- Cylinders and tanks can not be completely filled with liquefied gas, but only up to 85% – as a temperature increase of 1°C causes a pressure increase of 7–8 bar and may lead to bursting of the cylinder.

- Tanks must be supervised by UDT every two years, and every 10 years – internal revision and pressure testing must be done.


Cylinders for LPG

Division of gas networks due to the structure



- Branched
- Ring-shaped
- Mixed

Division of gas networks due to their functions

- Transmission high-pressure gas pipelines – over 1.6 MPa
- Supply
  - ✓ medium pressure – over 10 kPa, but less than 0.5 MPa
  - ✓ medium – elevated pressure – up to 1.6 MPa
- Distributing – medium or low pressure – up to 10 kPa;
  Diameter = 50–100 mm
- Gas connection: Diameter = 25–32 mm

Network objects

- The reduction station is the boundary between the transmission and supply networks.
- Supply network becomes distributing in a distributive building.

Source: RZOUG Gaz-Technika Sp. z o.o.

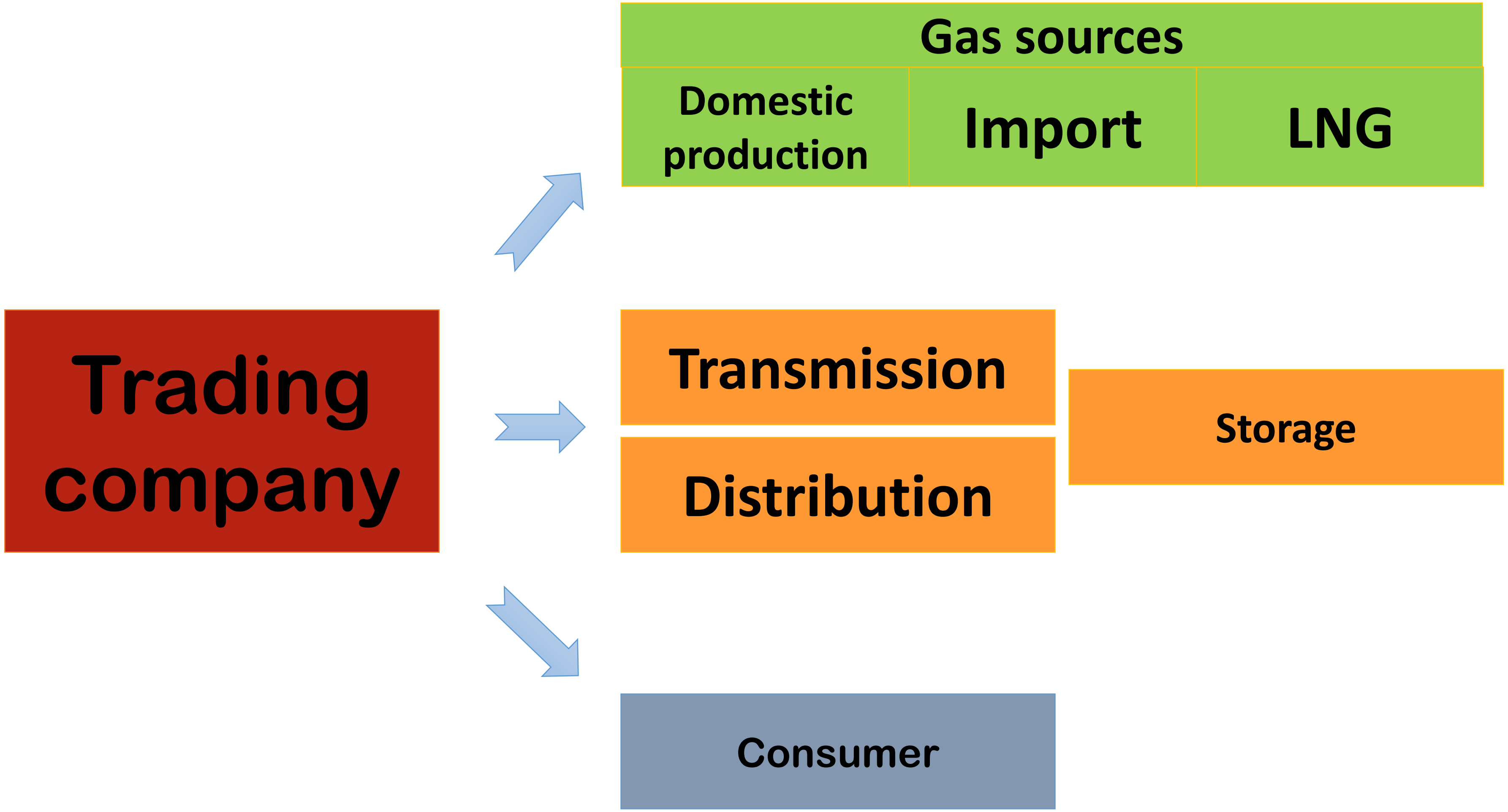
Location classes

1st class – Areas with residential buildings and public utility buildings, single- or multi--family buildings, intensive traffic, developed underground infrastructure, such as water supply, sewage, heating, gas, energy and telecommunications, as well as streets, roads related structures and mining areas.

2nd class – Terrains with single-family and farm buildings, development with individual recreation buildings, as well as the necessary infrastructure.

3rd class – Undeveloped land and areas where only single-family, farm and livestock buildings and infrastructure necessary for them may be located.

The gas market model in Poland



Trading company

Gas sources

Domestic production

Import

LNG

Transmission

Distribution

Storage

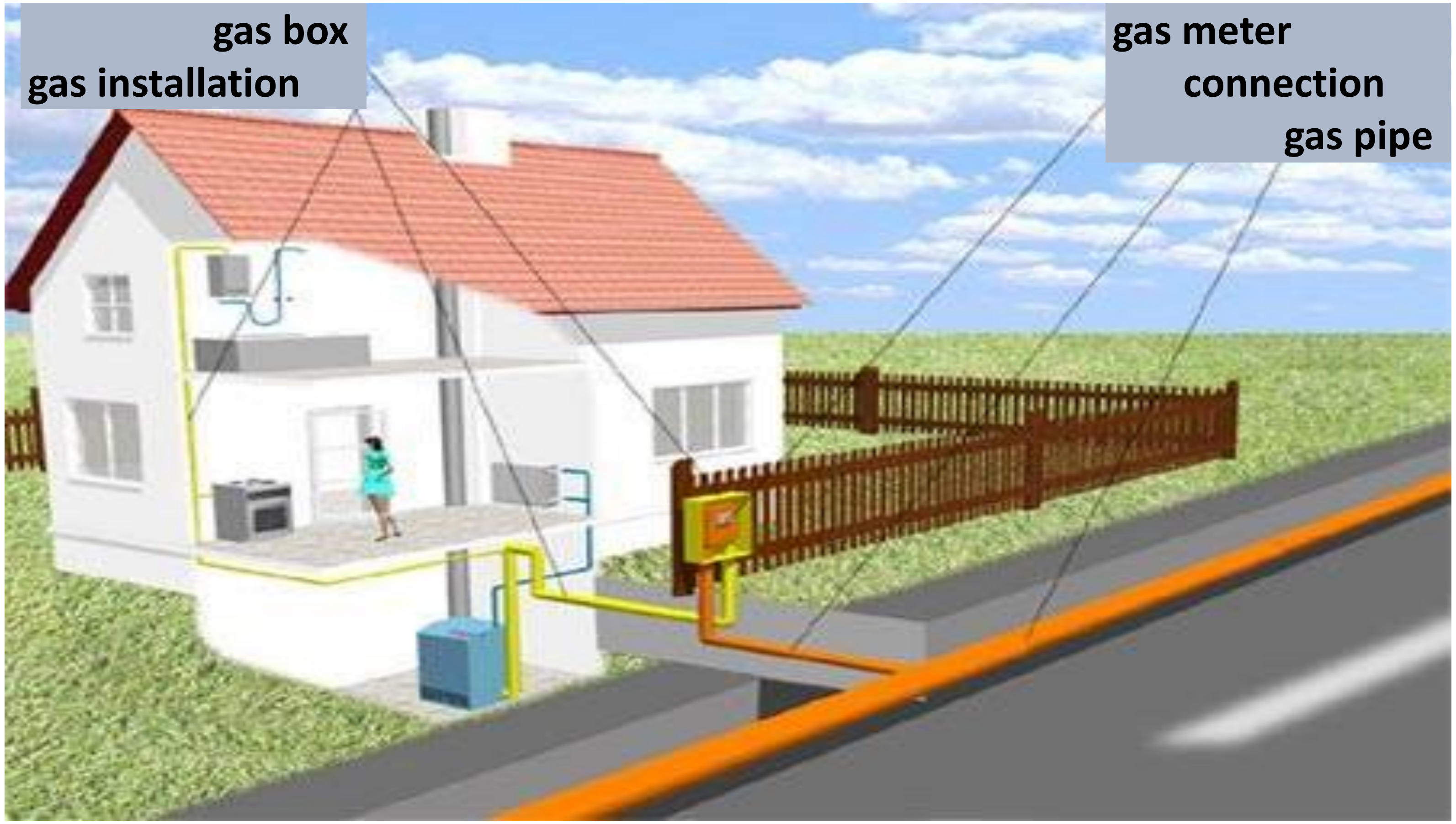
Consumer

The investment process

Construction of a gas network with gas connections:

- Gathering information about the **potential consumption** of gaseous fuel,
- Development of the gasification **concept** along with economic and technical analysis,
- Issuance of connection **conditions** to the gas network,
- Signing connection **agreements**,
- Execution of the gas network **project** with gas connections,
- Obtaining a **permit** for the construction of a gas network,
- Execution of the **gas network** with gas connections.

Network – connection installation



Internal installation

Construction of an internal gas installation:

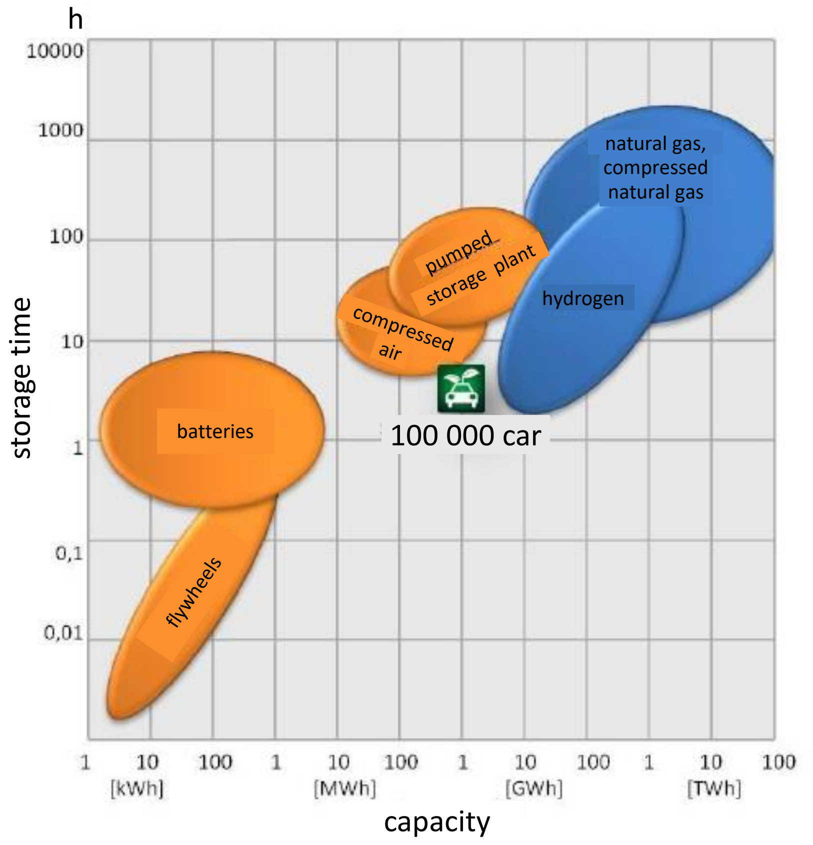
- Filling the **application form** for issuing the conditions for connection to the gas network,
- Execution of the internal gas installation **design**,
- Obtaining a **permit** for the construction of an internal gas installation,
- Execution of the internal gas **installation**,
- Signing a **contract** for the supply of gas,
- Gaseous **fueling** of the internal gas installation.

Advantages of a gas installation

- Clean operation of the heating device
- No storage required
- The payment is only for used fuel
- Comfortable service
- Constant operative readiness
- Short heating time

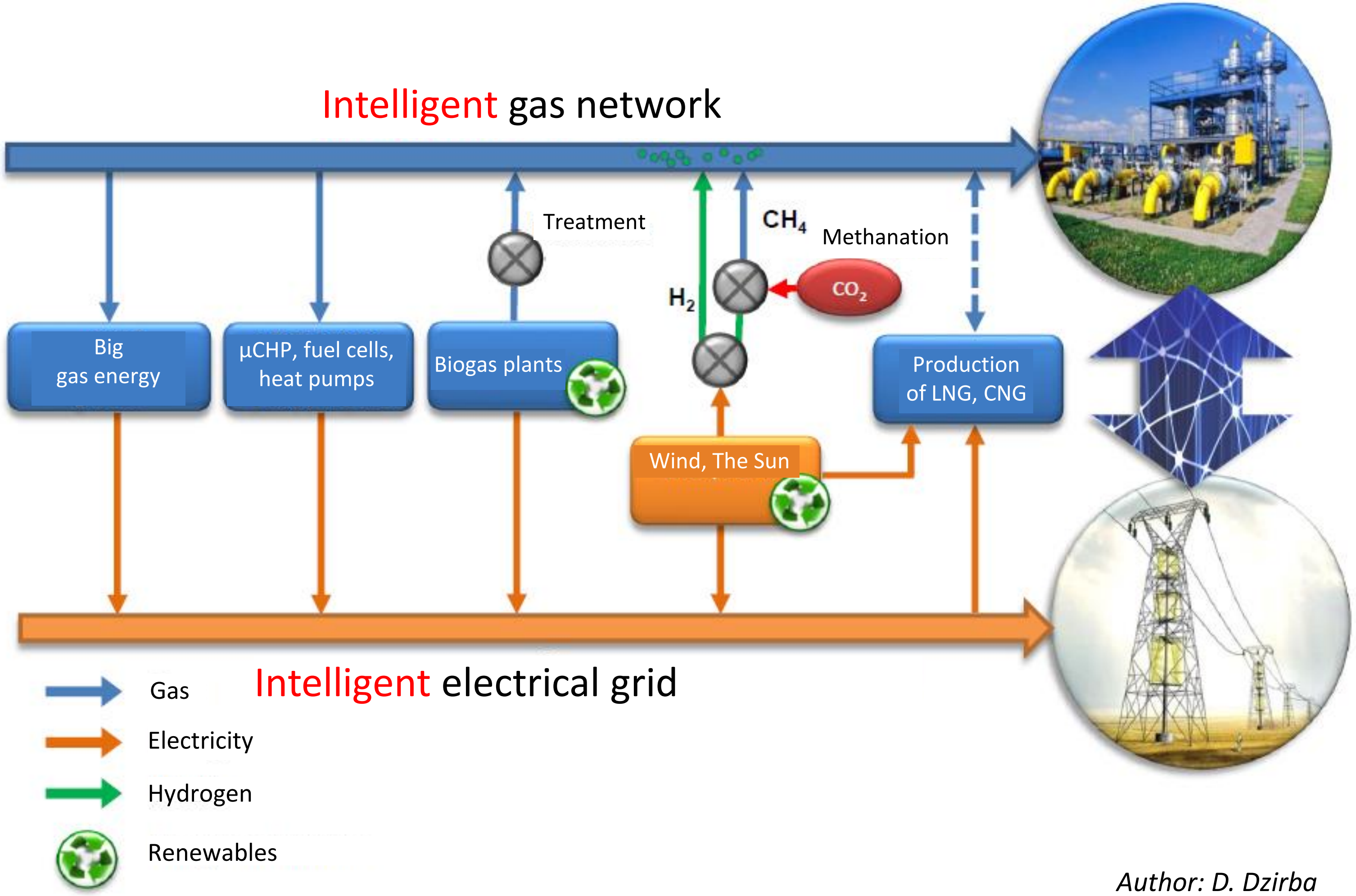
Energy storage in the gas system – a concept

- An excess of cheap energy can be used for the production of hydrogen (e.g. in an energy--consuming electrolysis process) that can be directly injected into the gas network or be a raw material for the production of methane in the methanization proces.
- Therefore, energy is transferred for use from one (power) system to another (gas), where it can be easily stored and used at a later time, or used to increase energy resources.



Source: Linke, 2011

Energy storage in the gas system – a concept



Intelligent gas network

Treatment

CH_4

Methanation

H_2

CO_2

Big gas energy

µCHP, fuel cells, heat pumps

Biogas plants

Wind, The Sun

Production of LNG, CNG

Intelligent electrical grid

Gas

Electricity

Hydrogen

Renewables

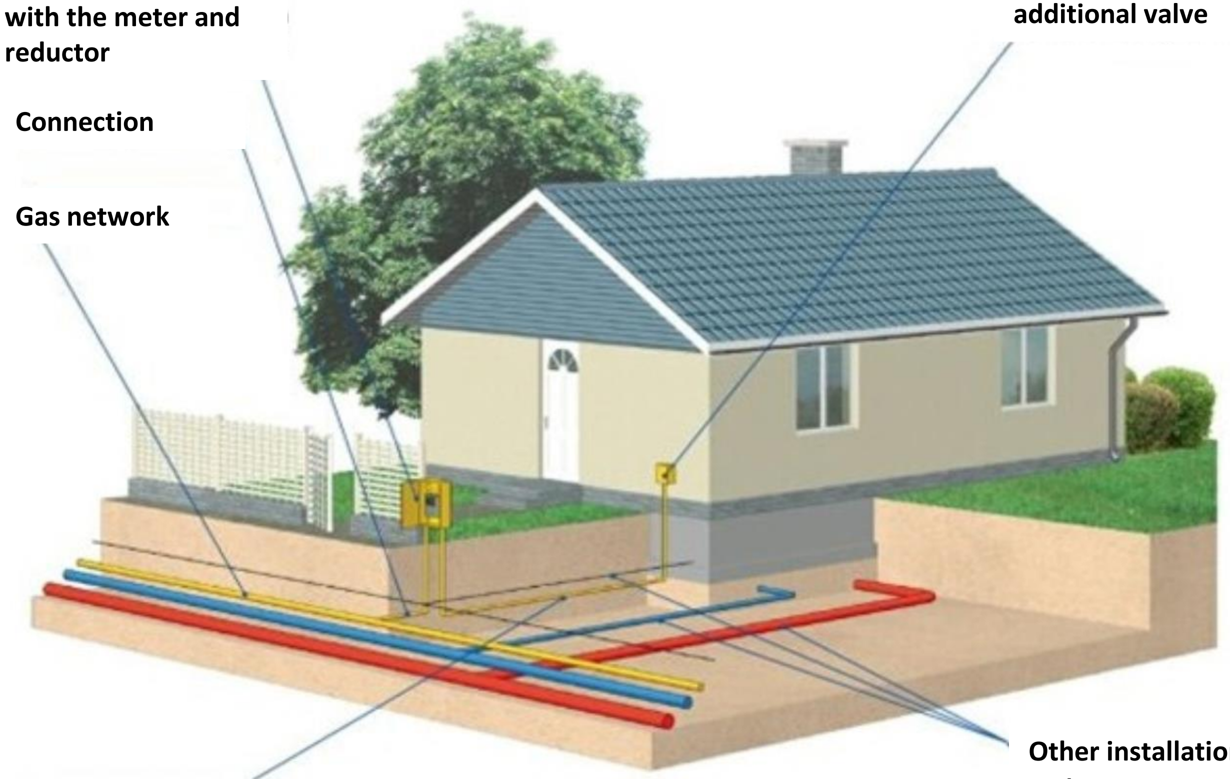
Author: D. Dzirba

How do we divide gas pipelines?

Pursuant to the Regulation of the Minister of Economy, gas pipelines are divided due to maximum operating pressures (MOP) for:

- gas pipelines of **low pressure** up to 10 kPa,
- **medium-pressure** gas pipelines above 10 kPa to 0.5 MPa in total,
- **medium high** pressure gas pipelines above 0.5 MPa to 1.6 MPa in total,
- **high pressure** gas pipelines above 1.6 MPa to 10 MPa in total.

Gas connection



Gas box in the fence with the meter and reductor

Connection

Gas network

User’s gas installation

Gas box with additional valve

Other installations e.g. water, sewage, power

Definition of connection

The gas connection is a section of the gas network from the last disconnection from the gas pipeline supplying to the main gas tap (included).

The main gas tap can be located:

- in an external cabinet on the building,
- in an interior cabinet in the building's wall,
- in a free-standing cabinet, located in the fence line from the street or general pedestrian route with access to it from the outside.

Definition of connection

In gas lines supplying gas to the external wall of a residential building, collective residence, public utility and individual item, there should be no pressure higher than 500 kPa, and to external walls of other buildings higher than 1,600 kPa.

In connecting the internal gas system to the medium pressure gas network, a pressure reducer should be incorporated within the gas connection box.

Basic information

The gas installation in the building should ensure the **supply** of gaseous fuel in the amount corresponding to the **needs** of use and the appropriate pressure before gas appliances, **depending on the type of gas fuel** used to power the building. According to specific Polish standards for gaseous fuels, this pressure should not be higher than 5 kPa.

It is forbidden to use LPG and gas from the gas network in one building. The gas installation of the building powered from the gas network **should have a main tap installed on the connection**, enabling the gas supply to be shut off.

Basic information

Gas connections made of polyethylene at the location of the main tap on the building wall are made according to the solution shown in the drawing. In this case, the gas connection to the building on the section from the gas supply pipeline to the distance of approx. 1.2–1.5 m from the building **is made of polyethylene**. At a distance of approx. 1.2–1.5 m from the building wall on the horizontal section of the connection, an **adaptive PE/steel fitting** is mounted and the further horizontal section of the connection, arch to the building wall and vertical to the main wall of the building **is made of steel pipe**.

Transition PE/Steel

Where to put the box?

The vertical section of the connection located on the wall of the building can be made in two variants:

- variant I – location of the connection directly at the building's wall and secured with a steel shield (sheet or pipe) or a PE pipe,
- variant II – location of the connection in the furrow cut in the wall, after subsequently being cemented over with lean concrete.

For brick buildings, option II is preferred, whereas for wooden buildings only option I is allowed.

NOTE – PE pipes of SDR 11 class 80 or 100 series should be used for gas connections.

Where to put the box?

The gas box

Author: P. Trojan

Variant I

1 – polyethylene pipe

2 – seamless steel pipe acc. to PN-80/H-74219

3 – warning tape

4 – inseparable connection steel/PE

5 – electrofusion sleeve

6 – locating tape with a metal insert

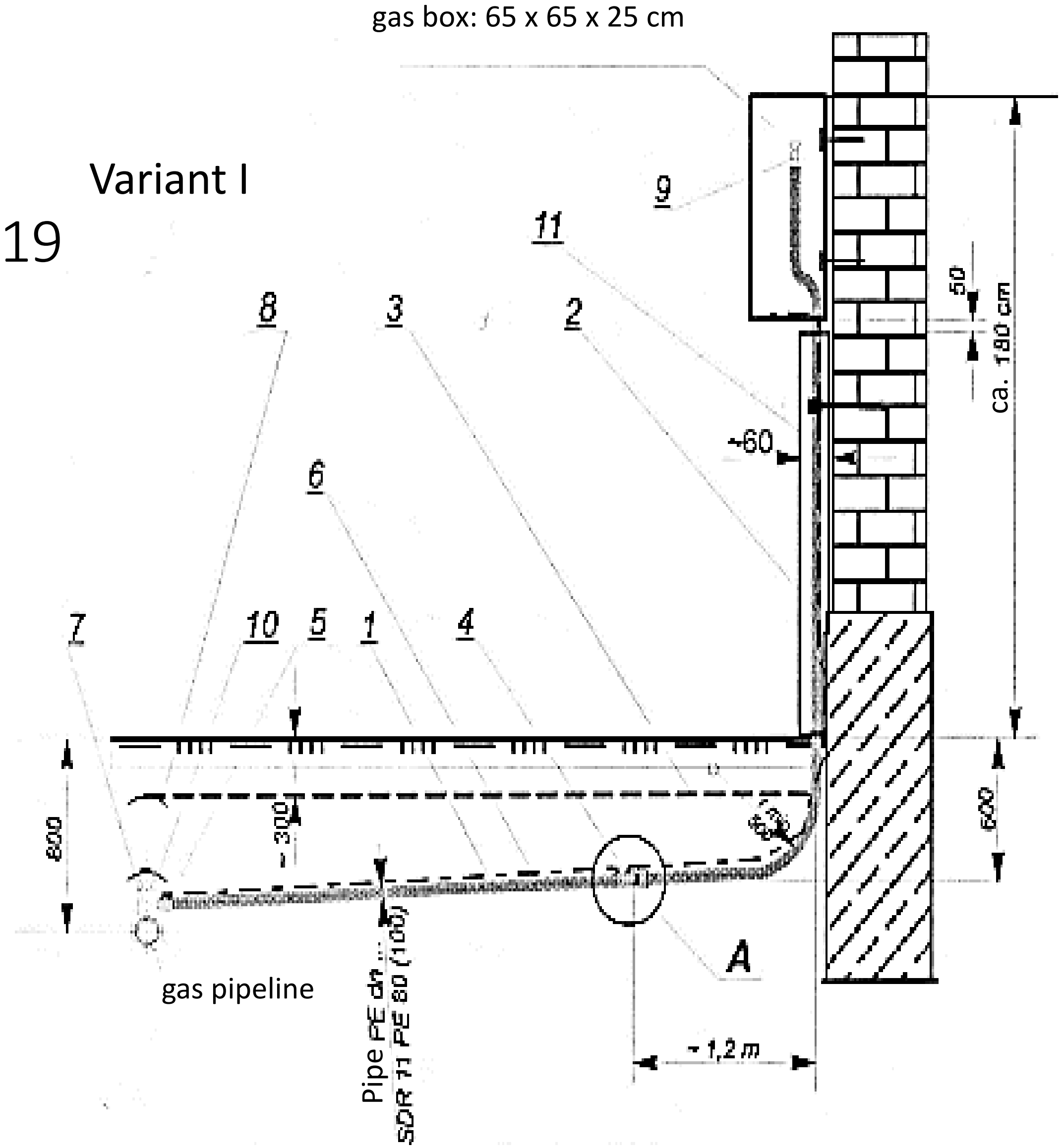
7 – tee saddle or russet

8 – gas pipeline warning tape

9 – gas tap PN 0.6 MPa

10 – gas pipeline locating tape

11 – protective tube



Variant II

1 – polyethylene pipe

2 – seamless steel pipe acc. to PN-80/H-74219

3 – warning tape

4 – inseparable connection steel/PE

5 – electrofusion sleeve

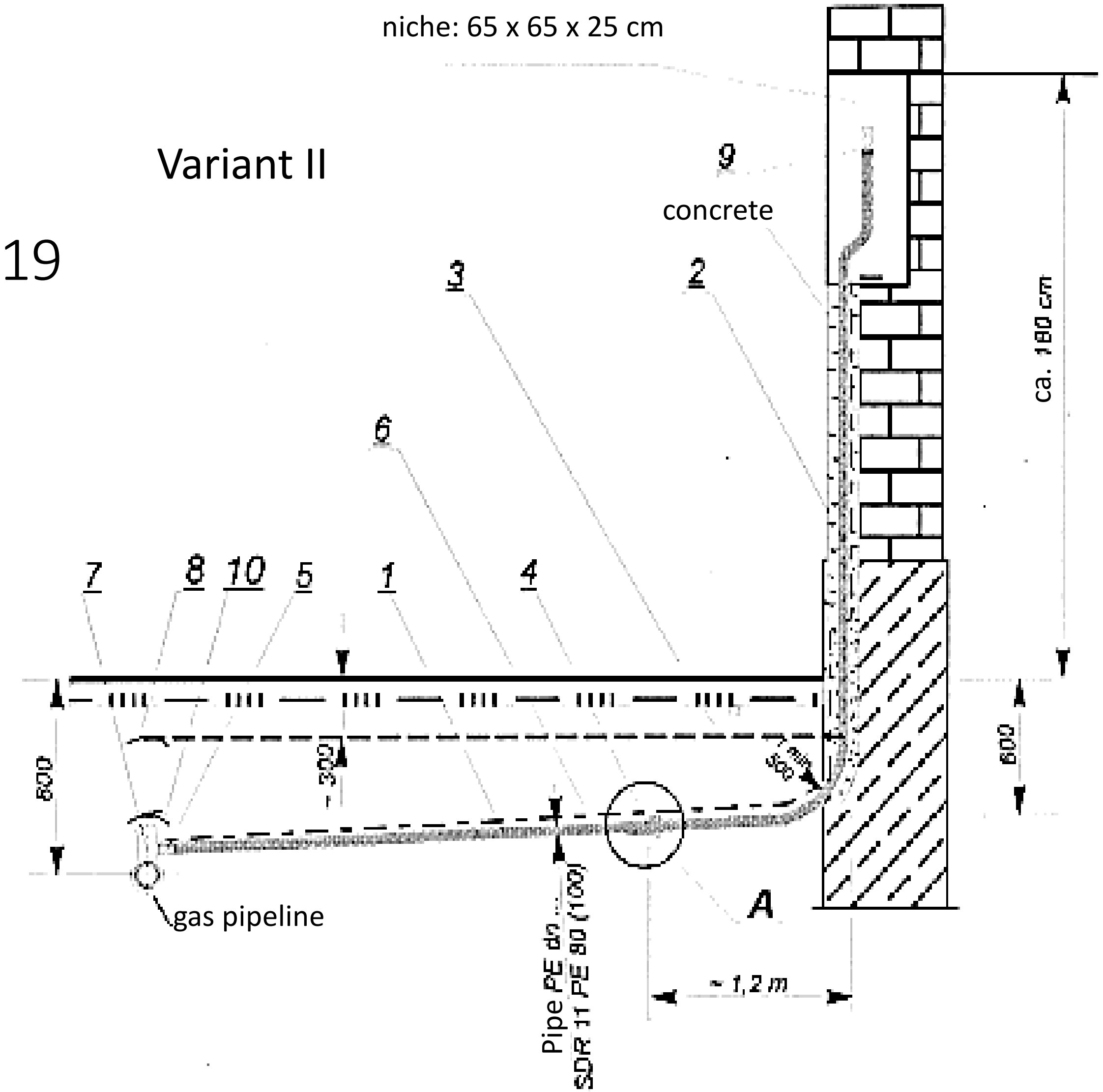
6 – locating tape with a metal insert

7 – tee saddle or russet

8 – gas pipeline warning tape

9 – gas tap PN 0.6 MPa

10 – gas pipeline locating tape

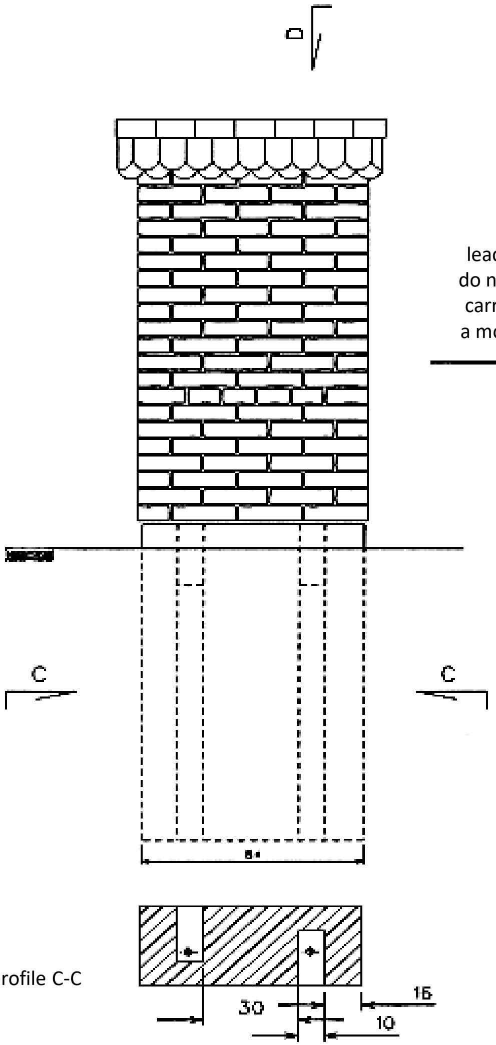


Gas connections with a main tap in a free-standing cabinet

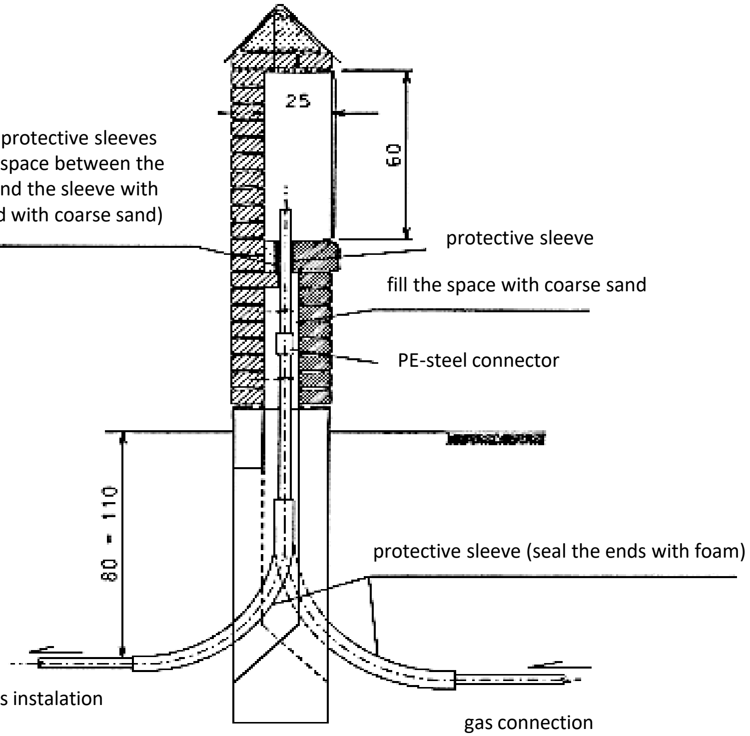
Currently, a popular way of making connections is locating the main tap with gas meter or reducer-gas meter in a **free-standing cabinet** located in the recipient's line of fence or directly on the recipient's plot (terrain).

An example of such a solution is presented in the subsequent slide, where the main tap was located in a free-standing cabinet located in a brick pillar of the property fence. In accordance with the requirements, the distance from the main tap to the building must not exceed 10 m. This provision does not apply to single-family housing and farm buildings.

Free-standing cabinet



profile C-C



lead pipes in protective sleeves do not fill the space between the carrier pipe and the sleeve with a mortar (mud with coarse sand)

protective sleeve

fill the space with coarse sand

PE-steel connector

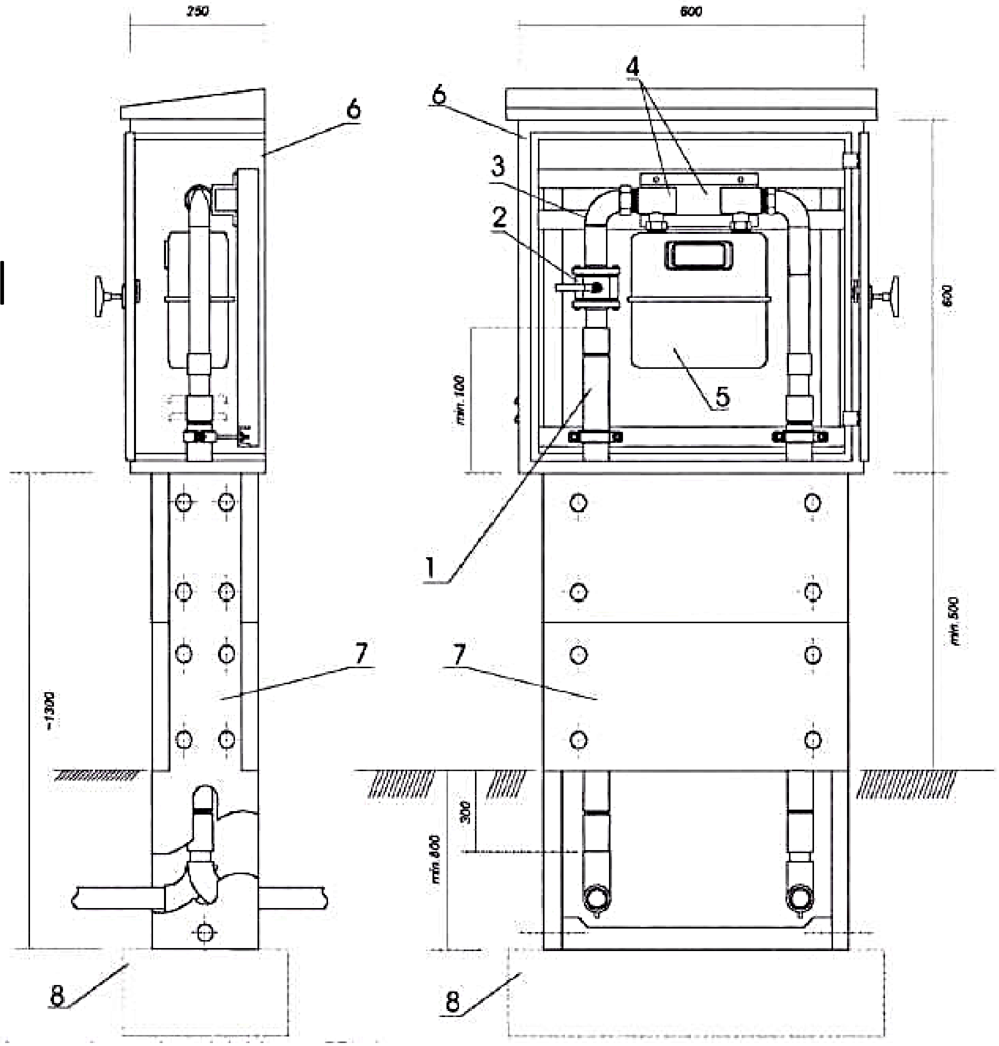
protective sleeve (seal the ends with foam)

gas instalation

gas connection

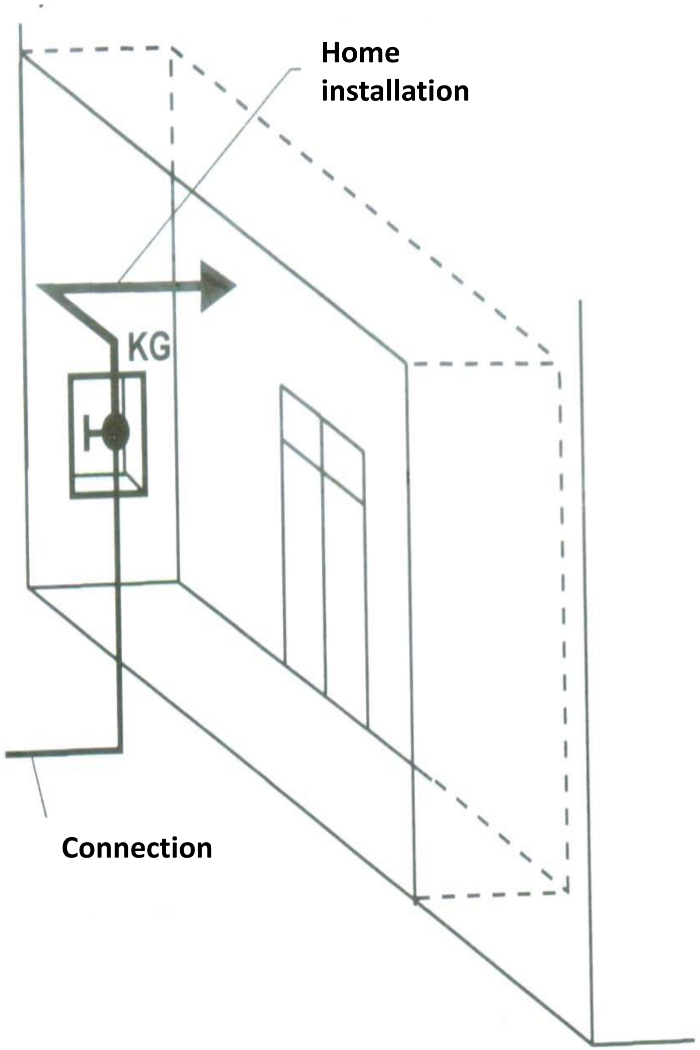
profile D-D

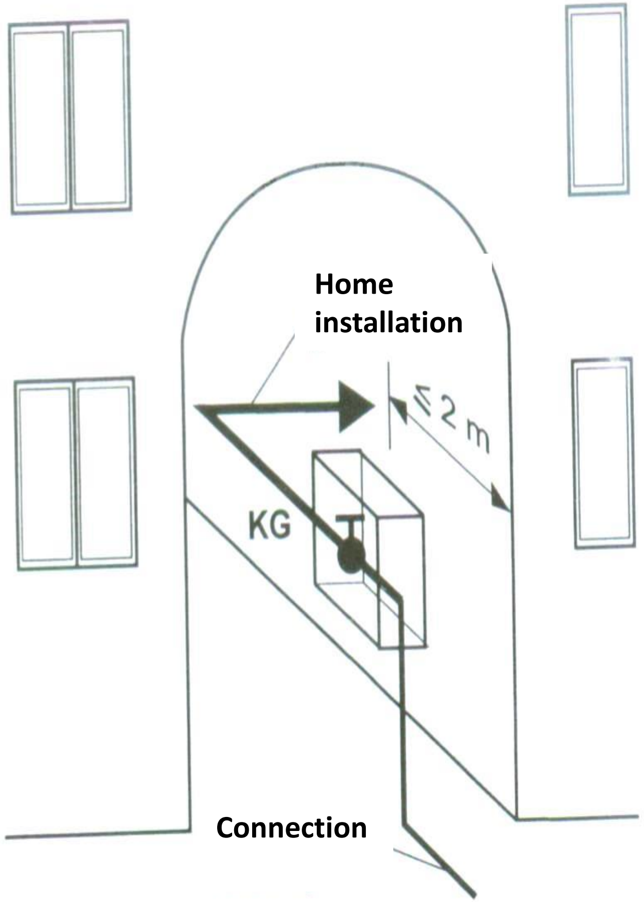
An exemplary solution of a free-standing gas cabinet on a low-pressure connection



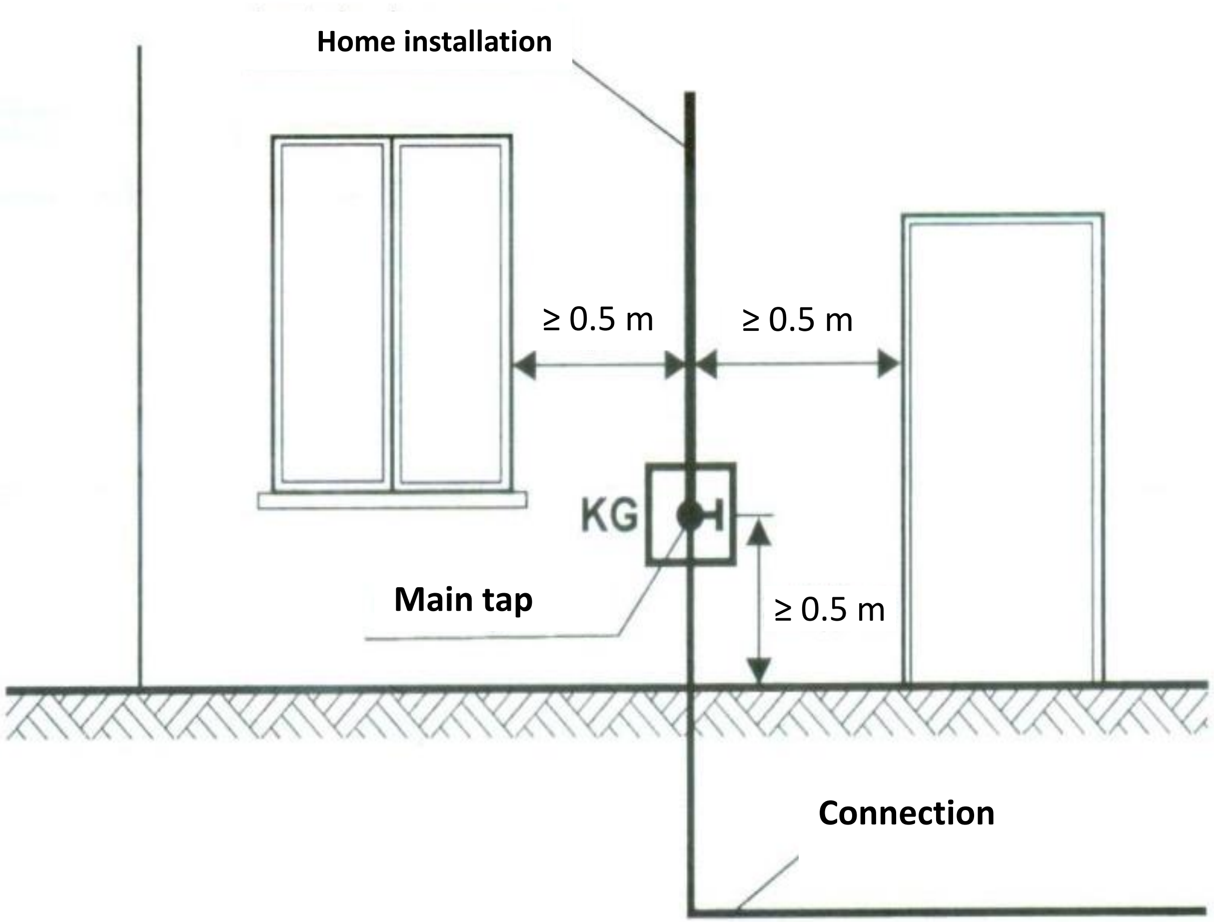
1 – column connection, flange connection PE/steel
2 – head main
3 – knee Hamburg – type
4 – manifold for gas meter with bracket
5 – gas meter
6 – holder
7 – concrete plinth
8 – foundation

Additional information about connections





Additional information about connections



Examples

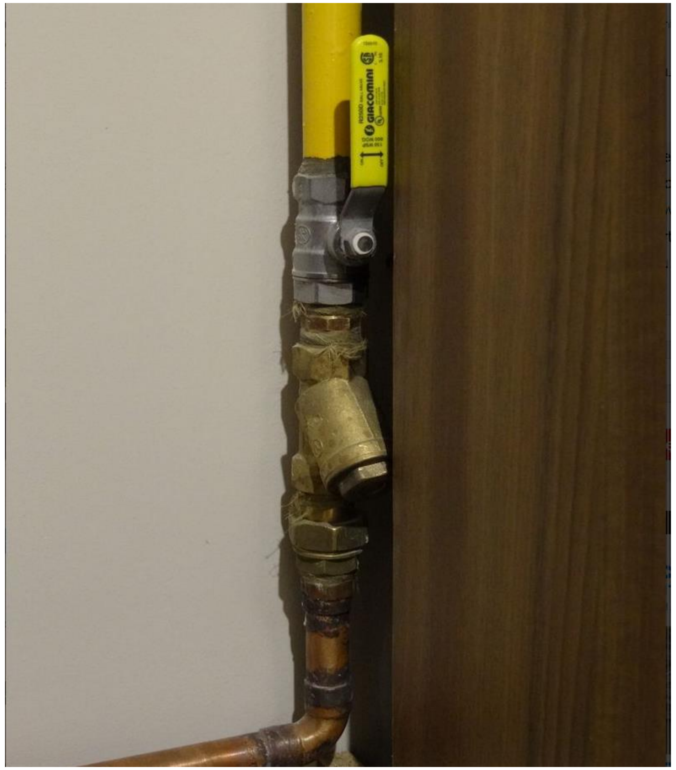
Gas box for one gas meter

Entrance of the gas installation to the building

Sources: www.poradnikprojektanta.com; www.pracowniasanitarna.pl

Interior installation

Bringing the installation to a dual-function gas boiler



Shut-off valve, oblique gas filter

Sources: www.poradnikprojektanta.com, www.pracowniasanitarna.pl

Interior installation

Sources: www.poradnikprojektanta.com, www.pracowniasanitarna.pl

Interior installation

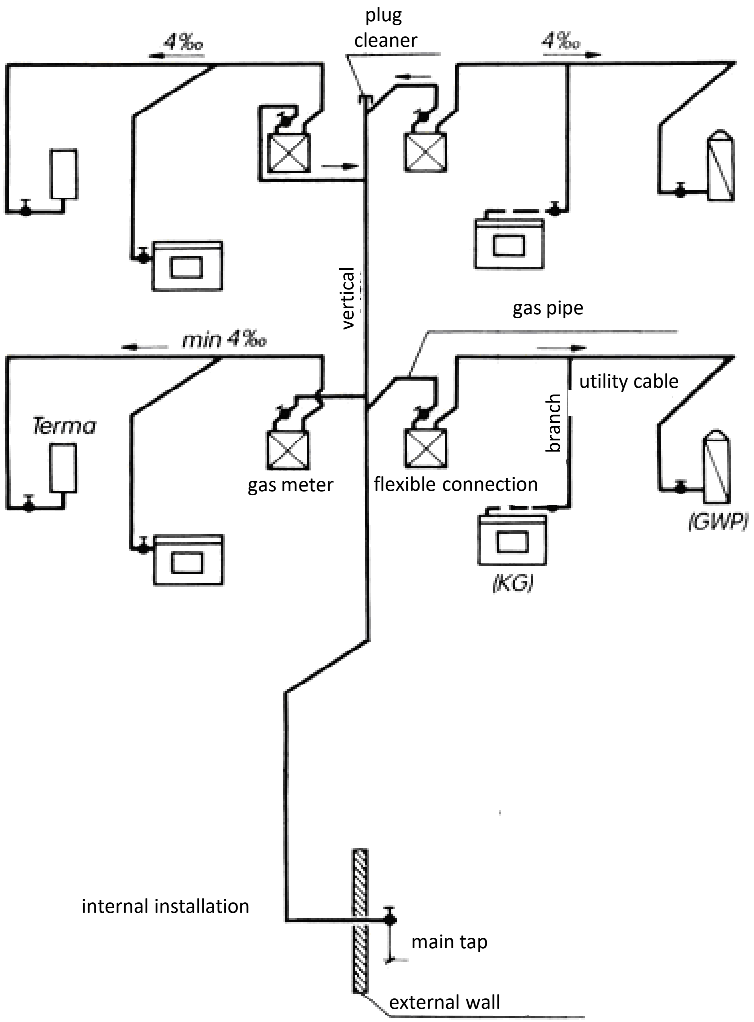
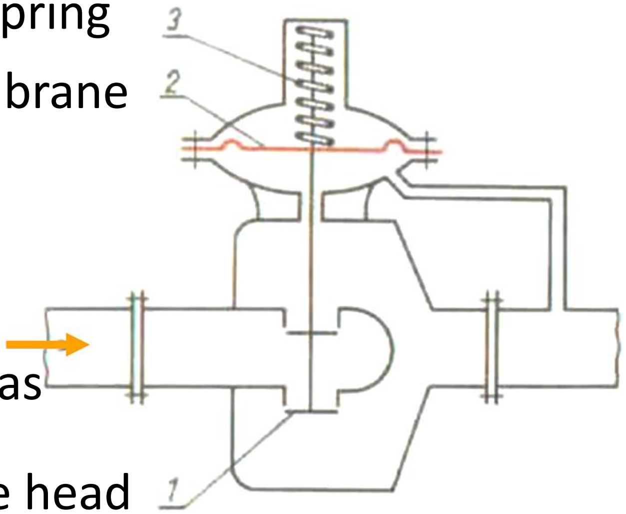


Diagram of the gas installation (KG) – gas stove, (GWP) – flow water heater

Interior installation

Gas pressure reducer



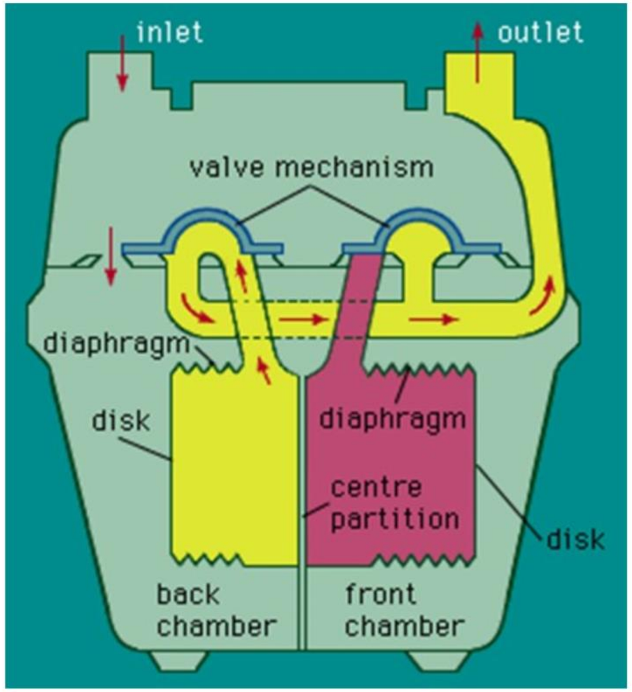
Spring

Membrane

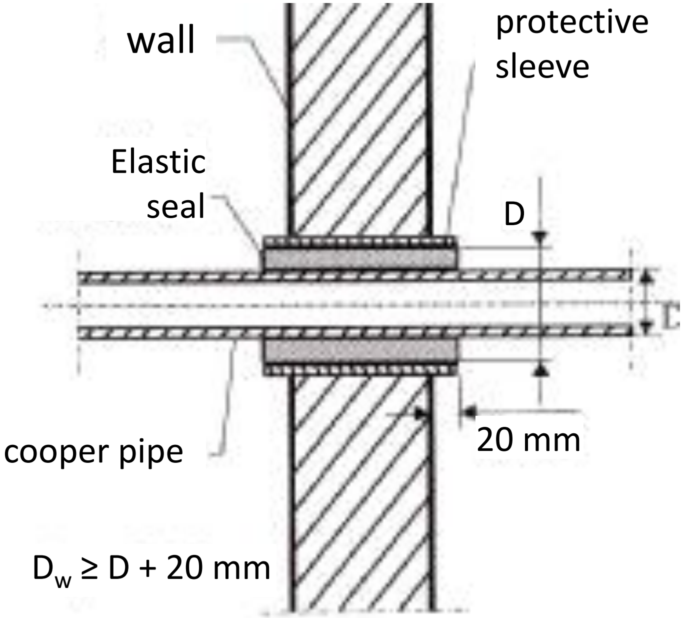
Gas

Valve head

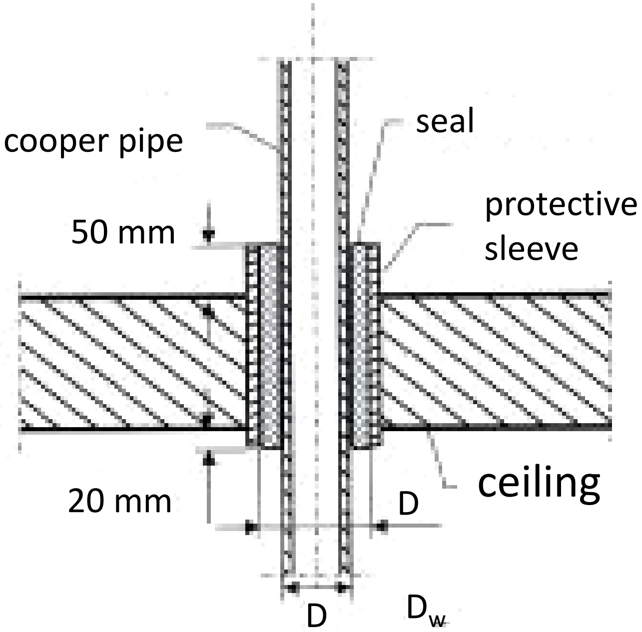
Bellows gas meter



Interior installation



Passage of the pipe
through the wall



Passage of the pipe
through the ceiling

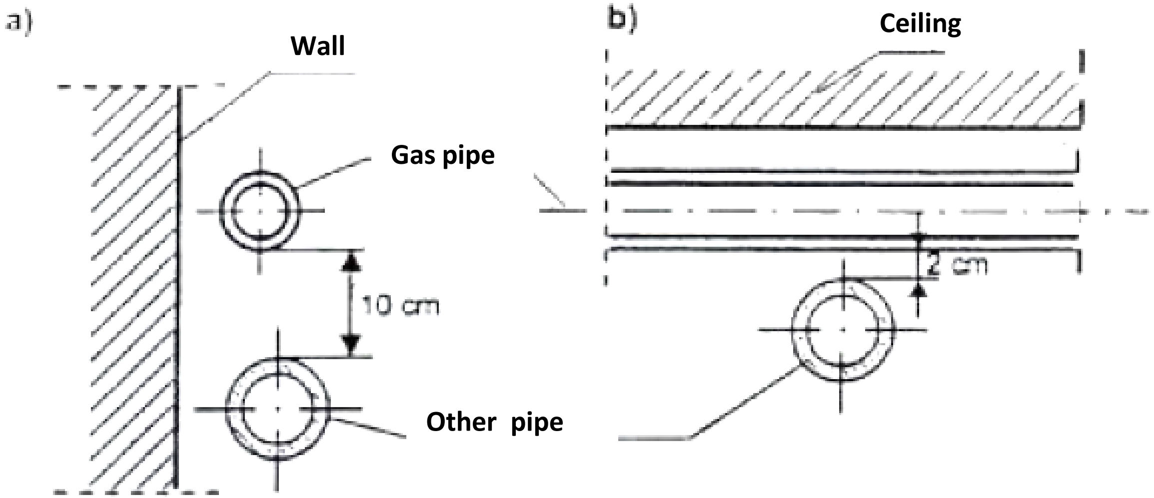
Interior installation

The pipes of the gas installation in relation to the cables of other installations constituting the building's equipment should be located in a way ensuring safety and ease of performing maintenance and inspection.

Minimum distances to wire and pipework are:

- 10 cm from plumbing pipes, sewage pipes, domestic hot water, central heating,
- 10 cm from electrical wiring (if the gas density is lower than air – above these ducts, if the density is higher – below),
- 2 cm when crossing over other installations.

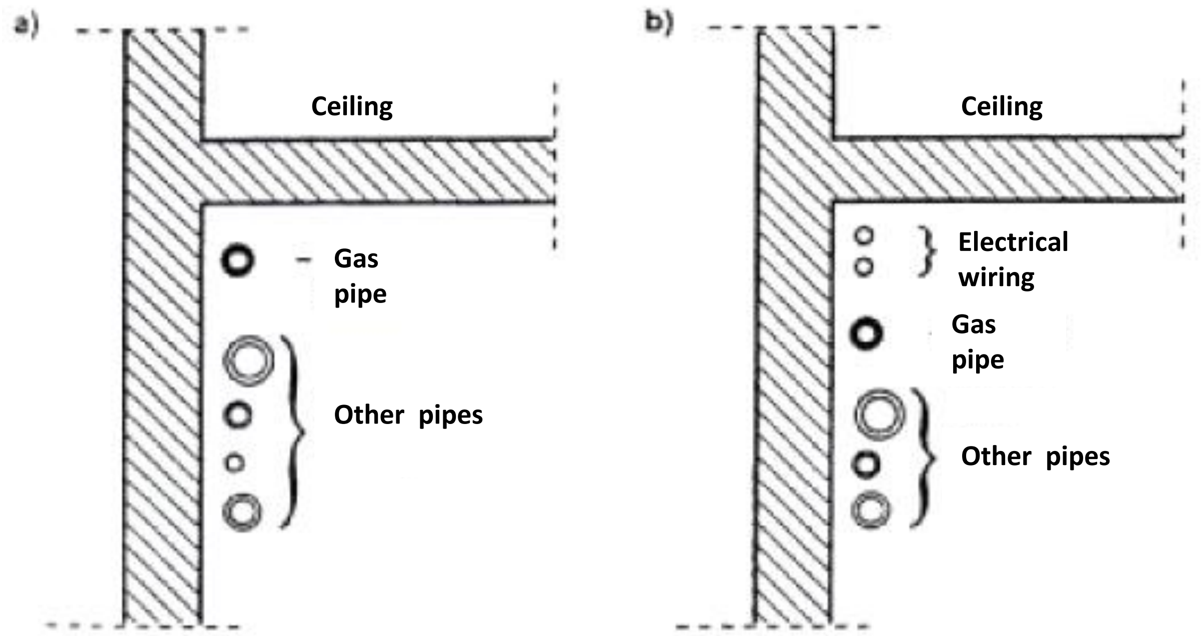
Interior installation



Minimum distances between gas pipes and other installations
a) paralel pipes, b) crossing pipes

Interior installation

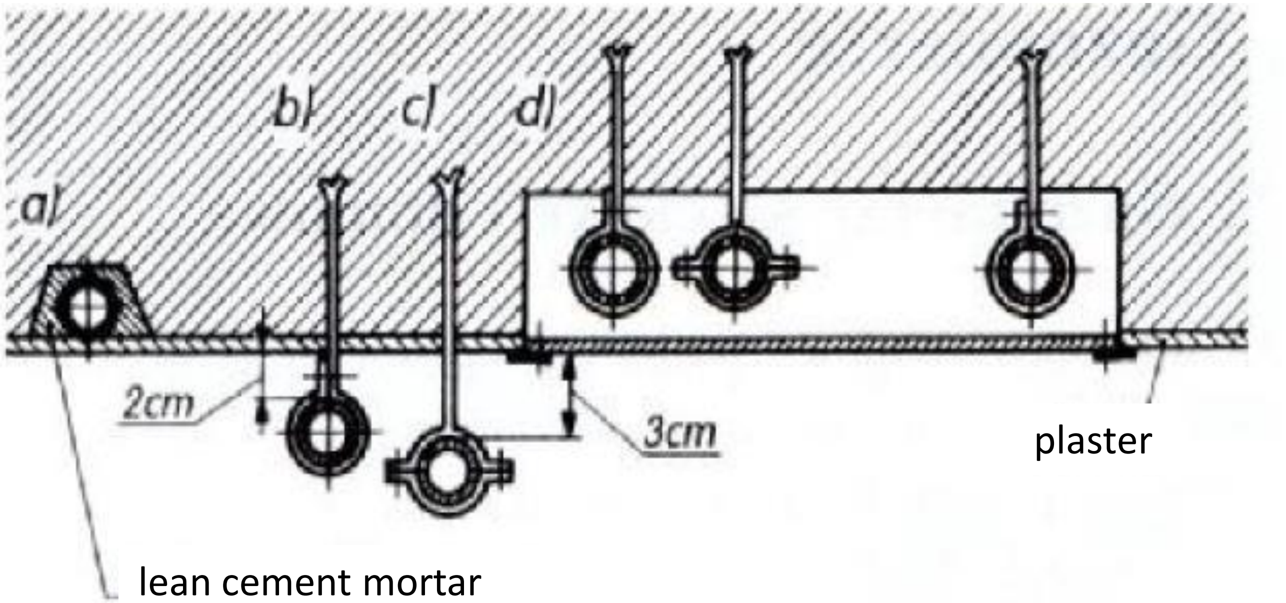
Location of gas pipes



Position of gas pipes relative to other installations
a) gas **lighter** than air, b) gas **heavier** than air

Interior installation

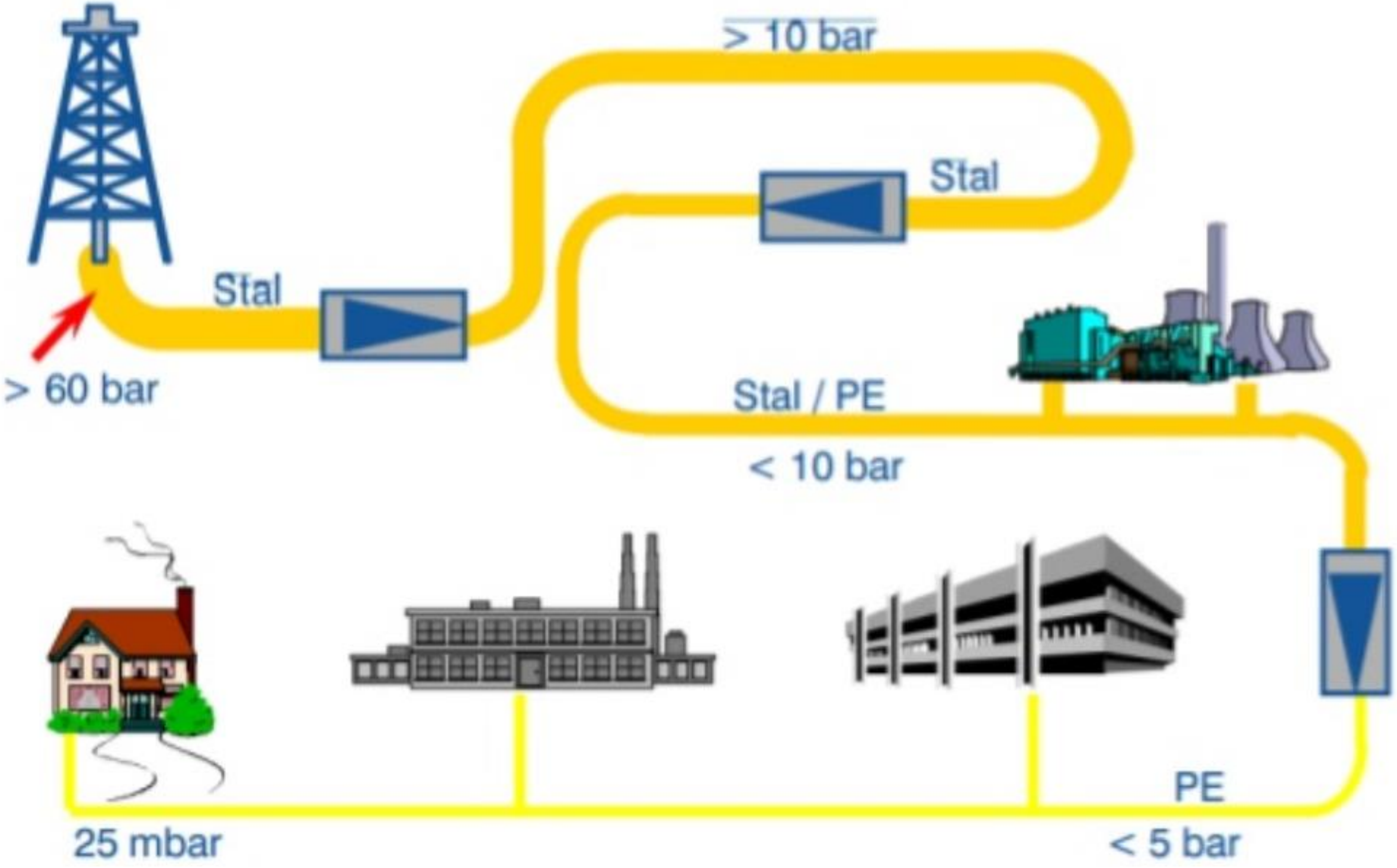
Ways of laying gas pipes



Ways of laying gas pipes:

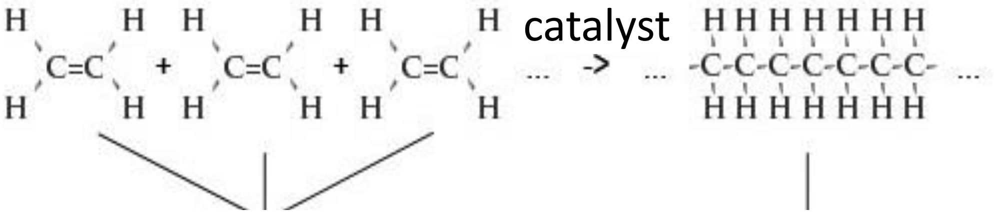
a) Vertical pipes in the furrow
b) On plaster with clearance 2 cm
c) On plaster in wet rooms with clearance 3 cm
d) In the collecting channel covered by a perforated plate

Materials for the construction of gas networks



What is POLYETHYLENE?

Polyethylene is a synthetic material, obtained by a chemical reaction called polymerization. Polyethylene monomers, which are simple organic compounds under the influence of catalysts and pressure, form macromolecules. The polymer obtained as a result of the synthesis is then processed. Pigments, antioxidants and various fillers are added to it to change its selected properties.



catalyst

nanomers

polymer

thus:

ethylene

poliethylene

What are the properties of POLYETHYLENE?

Polyethylene is characterized by:

- low density compared to other plastics,
- high toughness and significant elongation when stretched compared to steels,
- good dielectric properties,
- high chemical resistance,
- good processing properties.

Other properties of POLYETHYLENE

- Chain molecules tend to regularly stack themselves. Such regular structures are called crystallites, and those distributed in the amorphous area have a strong effect on PE properties, especially on density.
- Low density polyethylene LDPE (light density polyethylene) (910 to 930 kg/m^3) achieves a degree of crystallization from 40 to 50%, while medium density polyethylene MDPE or high density HDPE (940–960 kg/m^3) obtains molten crystallinity from 60 up to 80%.
- For the production of gas network elements, polyethylene with density above 930 kg/m^3 is used in accordance with ISO 1872-1. The increase in density leads to the improvement of tensile strength, elasticity, hardness and chemical resistance. The negative effect is the reduction of impact strength and resistance to brittle fractures.

Properties of POLYETHYLENE

Parameter	Polyethylene		
	High-pressure	Medium-pressure	Low-pressure
Density [kg/m^3]	915–926	930–940	942–965
Degree of crystallinity [%]	40–50	60–80	60–80
Tensile strength [MPa]	10–17	20–35	20–35
Elongation at break [%]	500–600	300–800	200–900
Melting temp. [^{o}C]	105–108	120–125	127–130
Hardness acc. Brinell [N/mm^2]	14–20	45–58	56–65

Properties of POLYETHYLENE

POLIETYLEN PE 500

(PE – HMW) High molecular polyethylene

- color: occurs as natural or colored
- durable temperature of use – 90°C
- density – 0.95 g/cm^3 (DIN 53479)
- yield point – 25 MPa (DIN EN ISO 527)
- tensile strength – 40 MPa (DIN EN ISO 527)
- elongation at break – >50% (DIN EN ISO 527)
- elastic modulus from the picking test – 1,100 MPa (DIN EN ISO 527)
- modulus of elasticity with bending test: natural – 900 MPa
- ball hardness – 52 MPa (DIN 53 456, ISO 2039/1)
- toughness (DIN EN ISO 179) – without breaking

Abrasion and abrasive wear

Toughness is called impact resistance of the material, and the measure is the ratio of the work consumed to the dynamic destruction of the sample to its cross-section at the site of destruction.

High impact strength is an advantage in transport conditions, e.g. pipes.
The phenomenon of **abrasive wear** is related to the abrasion of the plastic particles by the abrasive medium, e.g. sand, hard ground, etc.

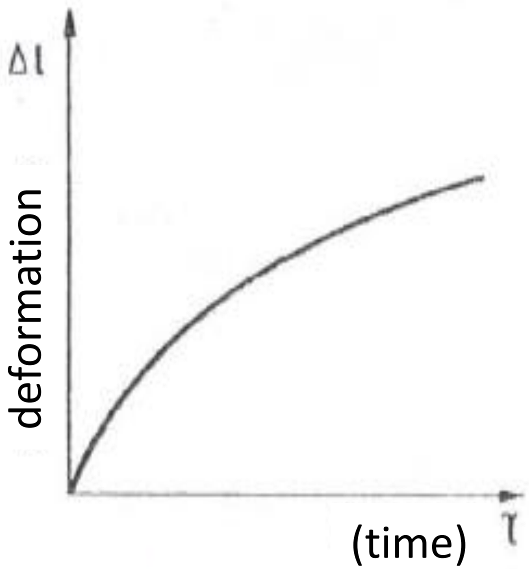
Heat influences the reduction of abrasion resistance. Lack of resistance to abrasive wear and scratches plays an important role when transporting plastic products, e.g. pipes.

Relaxation and creeping

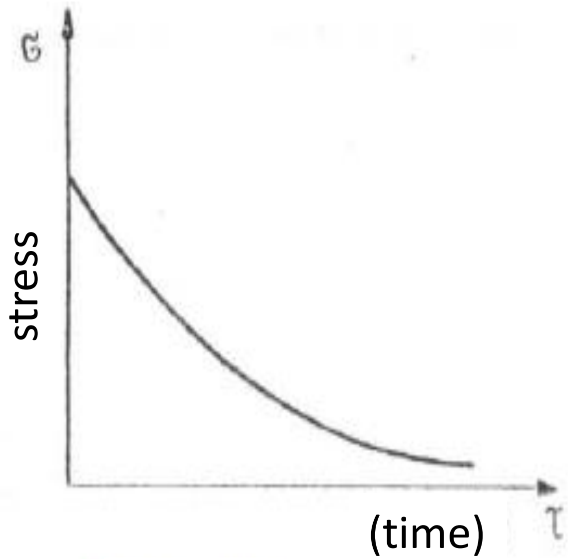
Relaxation – reduction of stresses at constant set strain

Creep – the change in the dimensions of the sample under constant load changes over time

Relaxation and creeping are simultaneous phenomena



creep



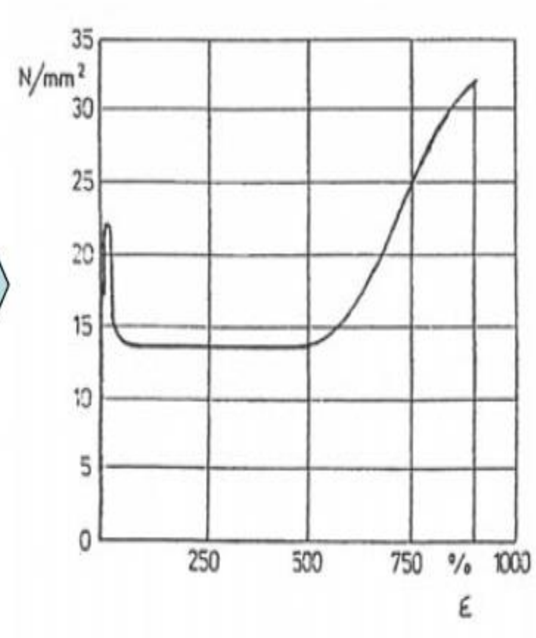
relax

Mechanical properties

Ultimate strength

If the element is exposed to stresses for a short period of time, e.g. minutes, hours, then these ares referred to as immediate strains

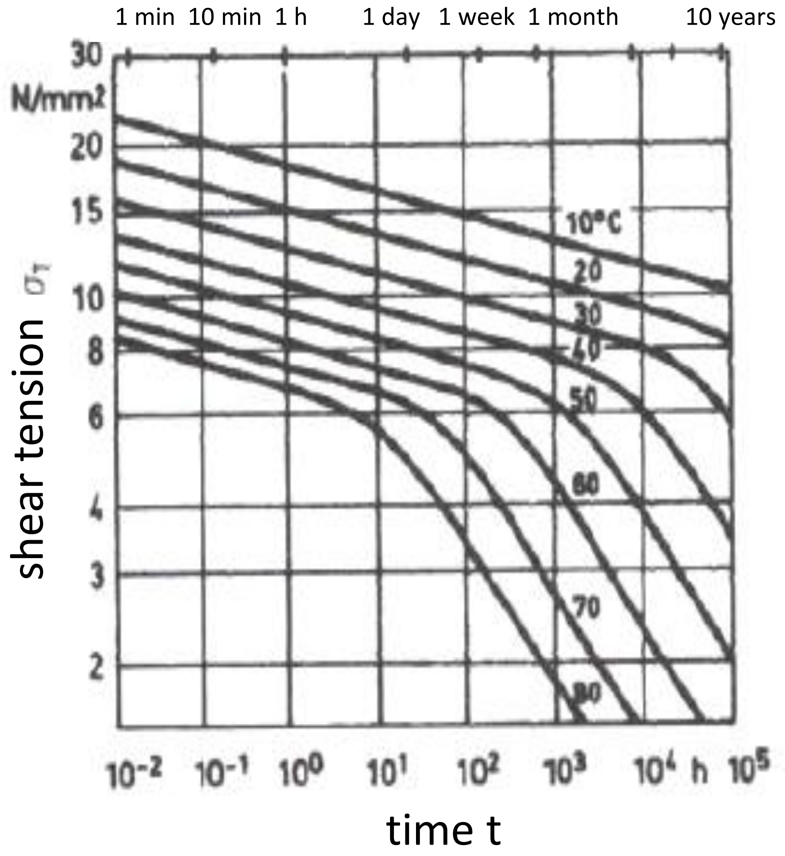
The course of deformation changes as a function of stress for HDPE. A typical graph for plastics showing the so-called cold flow (having a large elongation to breakage point)



Mechanical properties

Long-term durability

- Long-term strength tests measure the decrease of strength properties over time. The limit value of computational durability is 50 years.
- The tests are carried out using the principle of thermal-time superposition, from which it follows that increasing the temperature of the measurement is equivalent to shortening the life of the pipes.
- The following graphs are used for the tests: stress – time temperature.



What does SDR mean?

Numeric designation of a particular type of pipe, which is approximately equal to the quotient of the nominal outside diameter and the nominal wall thickness.

What is the difference between PE 80 and PE 100?

In the field of HDPE pipes, we differentiate different polyethylene materials. These groups are:

PE 63 (= MRS 6.3 MPa)
PE 80 (= MRS 8.0 MPa)
PE 100 (= MRS 10 MPa)

The term MRS means: Minimum Required Strength.

By PE 80 we mean PEHD, which at its temporary creep limit (50 years of durability) and 20°C temperature load and control water, creates a creep curve of at least 8.0 N/mm².

This intersection of PE 63 and PE 100 materials is respectively 6.3 N/mm² or 10.0 N/mm². This means that with the same dimensions, pipes made of PE 100 can be used at a higher working pressure than those made of PE 80.

What pressures can withstand pipelines?

C	PE 80		PE 100	
	SDR 11	SDR 17.6	SDR 11	SDR 17.6
2.0	8.0	4.8	10.0	6.0
3.0	5.33	3.2	6.67	4.0
4.0	4.0	2.4	5.0	3.0

According to current regulations, plastics can be used to build low and medium pressure gas pipelines.

C – coefficient of operation (design).

The coefficient has values greater than 1, and takes into account the operating conditions.

Overall operating coefficient (design) (C) and design stress (σ_S)

Design stress (σ_S)

allowable stress, in MPa, in a specific application, They are determined by dividing MRS by the coefficient *C*, i.e.

$$\sigma_S = \frac{MRS}{C}$$

The circumferential stress of the polyethylene gas pipeline, under static conditions, caused by the maximum working pressure (MOP), should not exceed the product of the minimum value of the required strength (MRS) and the design factor of 0.5.

Thermal expansion

When laying the pipe, its expansion should be taken into account. It can be calculated as follows:

ΔL = L * Δt * εt

Where:

ΔL – expansion in mm

L – string length in m

Δt – temperature difference °C

εt – Coefficient of thermal expansion mm/m°C

Average coefficient of thermal expansion for various pipe materials:

- HDPE = 0.20 mm/m°C
- PCV = 0.08 mm/m°C
- PP = 0.18 mm/m°C

For example:

- Material: HDPE
- Lenght L = 60 m
- temperature difference Δt = 15°C
- ΔL = 0.20 * 60 * 15 = 18 cm

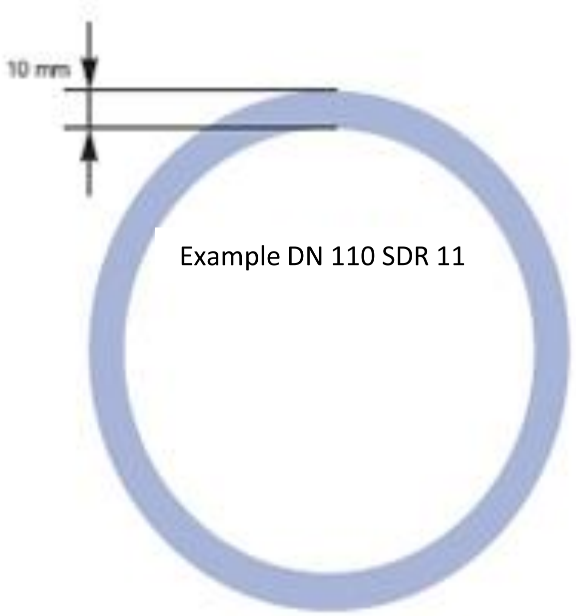
What are PE100RC materials?

- RC means resistance to cracks from the expression "Resistance to Crack". PE 100 RC is a PE 100 type raw material that exhibits the highest resistance against crack propagation. Stress cracks can occur through concentrated loads. When using PE 100 RC, this type of situation can be avoided thanks to their outstanding resistance to stress cracks.
- Critical pressure of rapid crack propagation – pressure in polyethylene pipes at which at 273.15°K (0°C) the longitudinal cracking of the pipe wall caused by external factors occurs rapidly.
- The crack propagation test is carried out according to the standard PN-EN ISO 13479 by INiG in Cracow.
- The nominal pressures declared by the suppliers of pipes are PN 7 for SDR 11; PN 6 for SDR 17.6 (max. PN 10 for SDR 11 with C = 2).

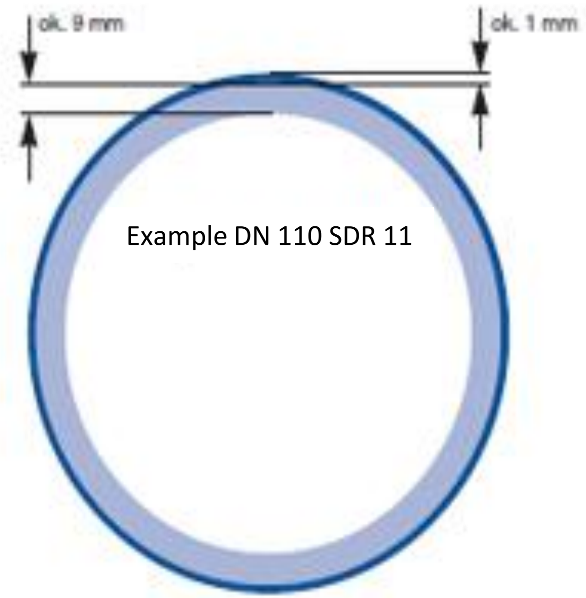

Nr. 02
12.04.07

Welding of PE pipes

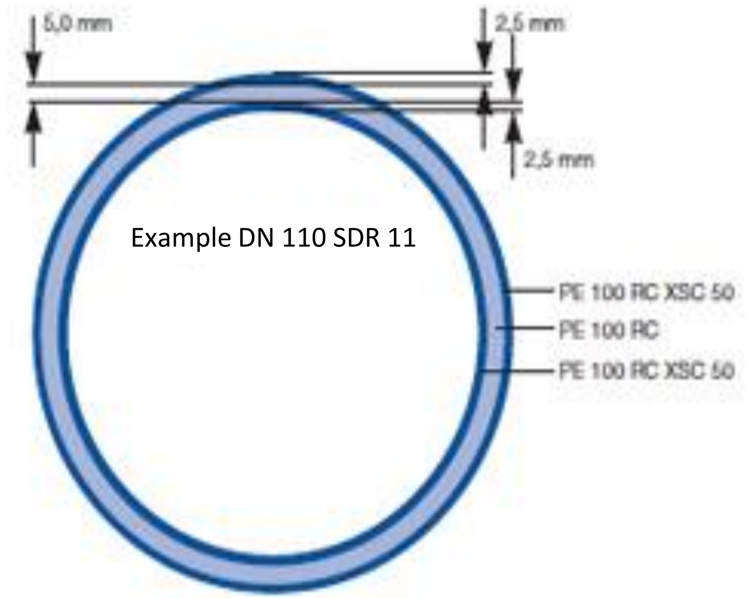
Construction of PE 100 and PE100RC pipes



contruction of the pipe type: PE100



contruction of the pipe type: Safe Tech RC_1



contruction of the pipe type: Wavin $TS^{DOQ®}$

Polyethylene pipes with increased resistance to scratching and PE 100 class PE spot loads are used in pipeline systems intended for the transmission of gaseous fuels. Allowed maximum working pressure is up to 1.0 MPa, taking into account the condition that the working pressure of the gas should not cause circumferential stresses greater than those specified for polyethylene PE 100, maintaining the C ≥ 2 safety factor.

HDPE pipes can not be used in interior installations of buildings.

In areas affected by mining activity, PE 100 class polyethylene pipes can be used in accordance with the conditions contained in the Technical Opinion issued on 2009/30/4 by the Central Mining Institute in Katowice.

- Designed for assembly (arrangement) without sub-ballast and sand bedding and for trenchless laying of pipes (controlled drilling). They do not require an additional shield pipe.
- From outside, 10% of normative thickness is made of orange polyethylene. As a result, it is possible to visually check the level of possible mechanical damage.

What is PAS-1075?

The PE100RC standard has not been covered by any Polish or European standards so far. The only attempt to systematize this field is the PAS-1075-4 (PAS = Publicly Available Specification) established in Germany:

Requirements PAS 1075-4 – "Polyethylene pipes for alternative pipe laying techniques – measurements, technical requirements and tests":

1) Notch Test according to PN EN ISO 13479. The sample withstands without damage for a period ≥ 8,760 h.
2) FNCT test (Full Notch Creep Test) – according to ISO 16770. The sample withstands without damage for a period ≥ 8,760 h.
3) Point load test according to Dr. Hessel. The sample withstands without damage for a period ≥ 8,760 h.

What is PAS-1075?

As proof of what positive STATEMENTS of the PRODUCTS tests and the certificate of their conformity with PAS 1075 should be presented (conformity of pipes with PAS 1075 can only be confirmed by the accredited Institute on the basis of tests carried out by the research unit for each of the three Dimensional Product Groups, after receiving permanent testing of tubes confirming their features (see items 1, 2, 3 above).

There are only two accredited Institutes in Europe that can test the compliance of products with the PAS 1075 guidelines, i.e. DIN Certco and TUV Sud. All pipe manufacturers that meet the requirements for compliance with PAS 1075 are listed on the websites of these accredited institutes.

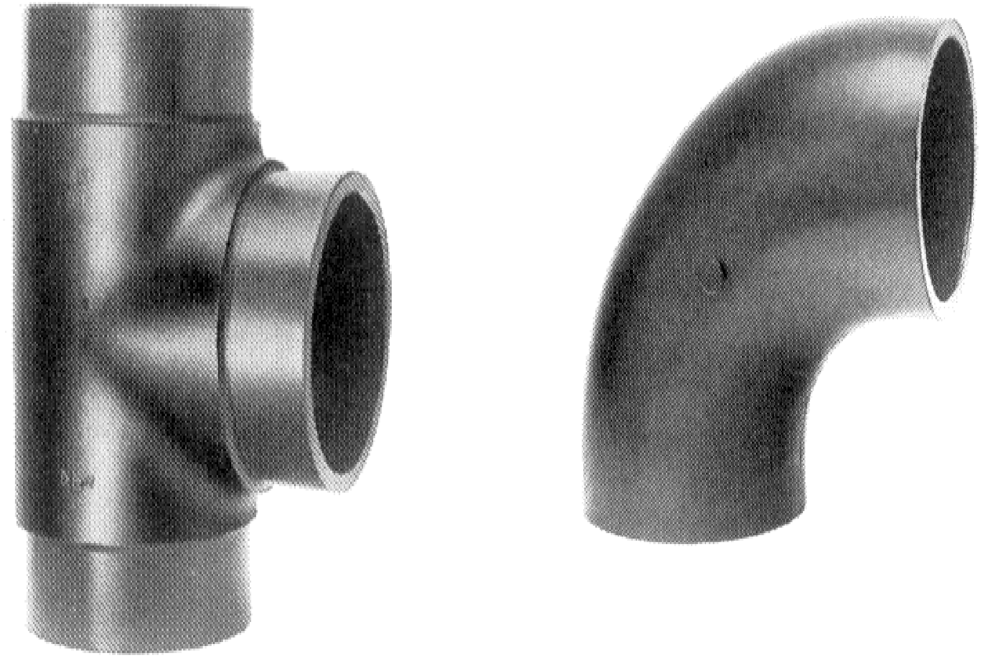
Based on this report, INiG at the request of the manufacturer issues technical approval confirming suitability in trenchless techniques and the possibility of assembly without sand bed and sand bedding, utilizing traditional and narrow excavation methods, as well as the possibility of trenchless renovation and replacement of water supply pipelines.

Connecting pipes

- There are various types of connectors in plastic gas pipelines. They are called "fittings" and "connectors". In contrast to steel pipelines, plastic connectors are ready-made elements, mounted at the construction site.

- Types of fittings can be classified due to the *function* (knees, tees, reductions, etc.), or *assembly technology* (fittings for electrofusion welding, butt welding, muff and saddle welding).

Butt fusion fittings



Butt welding fittings Standard angles of injected knees are 90^{o} and 45^{o}, reductions range from 3 to 5 diameters, reduction tees have departures with a diameter smaller than 3–5 ranges of the main diameter.

Butt fusion fittings

Saddle

Tee

Butt fusion fittings

- A characteristic feature of electrofusion fittings is the presence of a heating wire on the welded surface.

- Due to their functionality, they are readily used in all types of connections. However, special attention should be paid to the quality of fittings, because the savings made here often result in increased failure rates. A valuable advantage of electrofusion fittings is the possibility of using them as repair fittings and for switching on under full gas pressure. The diameters of electrofusion fittings produced range from 20 mm to approximately 630 mm.

Marking of pipes

Each pipe must be marked permanently. On the surface there should be a caption containing basic information necessary to identify the pipe. This information can include:

- pipe manufacturer's name or symbol,
- the number of the standard (PN-EN 1555-2),
- the word 'GAS',
- PE class,
- pipe dimensions (diameter x wall thickness),
- designation of a series of dimensions (for dn bigger than 40 mm),
- date of production,
- product code (extruder number, lot designation, etc.),
- safety mark 'B'.

Example marking: XXX PN-EN 1555-2 GAS PE100 110x10 SDR11 ddmmrr nnn xxx

Gas installation design in 25 steps

1. Familiarize yourself with the **technical conditions** of connection to the gas network.
2. Familiarize yourself with the current **map for design** purposes.
3. Familiarize yourself with **architectural projections**.
4. Reconcile with the architect (or investor or other customer) the **number and location** of the gas receivers.
5. Calculate the gas **demand** considering the simultaneous consumption of gas by all gas receivers.
6. Check whether the gas demand complies with the issued technical conditions (gas demand is less than or equal to the value given in the technical conditions). If everything is correct, you can proceed to the next stage if not, a plan of action must be undertaken with the customer, i.e. change of technical conditions, liquidation of part of the receivers, change in the capacity of some of the receivers – if conditions allow).

Gas installation design in 25 steps

7. Draw all gas receivers, their power and hourly gas consumption on plans.
8. Draw installation routes in plans.
9. Mark the gas installation divisions.
10. Draw an external gas installation from the pressure reduction point to the building.
11. Mark the ventilation and exhaust ducts on the plans. The ducts should meet the requirements of the technical conditions quoted at the very beginning of the documentation.
12. Draw a simplified calculation scheme – one-line deployment development.
13. Describe in the plans and in the calculation table the pre-accepted diameters and material of the installation. The initial diameters of gas pipes can be adopted on the basis of tables included in the literature on gas system design.
14. Check the gas meter selection. In the case of single-family housing, where the gas consumption is not greater than 10 m^3/h, the gas supplier imposes the type of gas meter.

Gas installation design in 25 steps

15. Determine the route of the gas installation for which you will perform hydraulic calculations. For this route (most often it is the appliance furthest from the main valve), perform detailed hydraulic calculations.
16. Knowing the volume of gas flow within individual sections and predefined diameters, calculate the linear and local loss on individual sections.
17. Add to the calculations the correction resulting from the difference in levels, resulting from the difference in gas and air density (recovery or loss of pressure on the vertical).
18. Knowing the pressure loss resulting from the flow resistance, maximum pressure loss on the gas meter and pressure recovery on the vertical – calculate the actual pressure loss in the system. Check if the total pressure loss is less than the permissible pressure loss in the system. The actual pressure drop in the installation is on average between 80 and 140 Pa. Remember to not oversize the installation unnecessarily. For gas installations powered by high-E gas (GZ 50), the maximum pressure loss is 150 Pa, and for gas GZ-35 this is 100 Pa.

Gas installation design in 25 steps

19. If the pressure loss is too high, correct the pre-accepted diameters and perform the calculation again.
20. Mark the final diameter of the gas installation on the plans.
21. Draw the final development of the gas installation.
22. Apply the remaining installations to the foundation. It is best to mark the foundation and other installations with gray color, and the designed gas installations with black or red color.
23. Send the project to the architect for the purpose of inter-branch coordination.
24. If you are doing a project for an architect, print the project in 4 copies and submit the complete documentation.
25. If you are in the field of obtaining a building permit, obtain from the Investor a declaration on the right to use the property for construction purposes and a power of attorney to submit an application on behalf of the investor.

Source: https://poradnikprojektanta.pl/projekt-instalacji-gazowej-w-25-krokach/

Part 2

Construction and maintenance

Preparation and organization of the construction

Requirements for the gas pipeline during construction

The gas pipeline must be made so as to withstand:

- internal pressure,
- anchoring and filling in the gas pipeline,
- road or rail traffic,
- loads during assembly,
- pressure tests,
- loads caused by the mass of water, if the gas pipeline is located under the river,
- the impact of connected branches,
- loads resulting from water pressure as a result of flood, icing, snow,
- land subsidence,
- soil erosion,
- stresses due to temperature difference.

Pipe transport

- The pipes are delivered in sections of 5 m, 10 m and 12 m length or in circles of 100 m or more. Coil can be rolled into pipes with a diameter of up to approx. 160 mm, pipes with diameters up to 63 mm are normally supplied in coils. The outside diameter of the coil should be 25 times larger than the nominal diameter, but it must not be less than 600 mm.
- Means of transport used for transporting pipes must be specially adapted for this purpose. Cargo boxes must not have sharp, protruding edges, nor protruding nail points, metal sheeting or other objects that may damage the pipes during transport or unloading.

Pipe transport

- The length of the box must be matched to the length of the pipes being transported, as it is unacceptable to load the pipes on the logs.
- Slings must not damage the surface of the pipes. It is forbidden to eject pipes from the lower layers and drop them from the load box.

Storage of pipes

- Due to the tendency to creep, the height of pipe laying in sections is limited up to approx. 1 m.
- Pipes in coils should be stored flat at a maximum height of 1.5 m.
- The storage temperature should not exceed 40°C.
- It is forbidden to set coils vertically against the wall on a concrete or stony base, as this causes a strong deformation of the pipe and pressure of the surface.

Storage of pipes

- The pipes when supplied by the producer in bundles and secured with wooden staves can be stored at higher heights, but when laying, reinforcements should be placed on themselves.
- Pipes should not be stored for longer than 2 years. In the case of pipes exposed to radiation and precipitation, the storage period is no longer than 1 year.

Designer and supervision qualifications

- Works related to the design and supervision of the construction and installation of polyethylene gas networks **should be performed only** by persons with appropriate qualifications, specifically those who hold a statement of professional preparation in their construction and installation.

- In addition, these persons must have a **certificate** of belonging to the appropriate chamber of professional self-government – the Chamber of Civil Engineers.

Staff qualifications

- Persons performing connection work on gas networks made of PE should have qualification certificates, and have completed the course for PE pipe welders, in a training center recognized by the gas company, and must also hold a valid E qualification certificate entitling him/her to operate the gas network that is issued by the qualification committee appointed by the Energy Regulatory Office.

Preparatory work

- After **collecting** all materials in accordance with the specification included in the project and **completing** formal and legal requirements, the task implementation process begins.
- If the design envisages butt and electrofusion welding technologies, **two independent equipment assemblers** equipped with the equipment will be necessary. Two people will be required to assemble pipes with a diameter of up to 63 mm, for three or even four people for larger diameters.
- It is necessary that at least two people be present during the excavation work.

Preparatory work

- It is most advantageous to carry out welding **at the edge** of the excavation. Any work carried out **inside** of it is a particular threat to the quality of the weld, due to the limited space. In any case, under the welder, hydraulic unit and plow with the heating plate, plank/plywood platforms should be placed so that the pipe mounting system **does not lie directly on the ground**, especially on grass, sand or clay.
- Providing a wind shield is particularly important. Even a small wind or gusts from passing vehicles, when welding on the sides of the road, cause a rapid drop in the temperature of heated surfaces when removing the hob.

Equipment

- The basic equipment will be appropriate welding machines and power generators. However, taking into account the possibility of welding in sub-zero temperatures, during rain or wind, the pipe laying team should be equipped with tents, screens and hot air blowers.
- It is recommended that tents or screens be made of transparent foil. In addition to this basic equipment, tools and auxiliary devices will be necessary, including cutters, shears, two or four-jaw handles, platforms, rollers, scrapers, etc. This equipment is to shorten the task's time, which is the main advantage of this technology.

Installation work

- Ideally, all assembly work is done outside the excavation. In many cases this is not possible, especially in built-up areas, due to the presence of other utilities. This possibility should be taken into account at the design stage. As a consequence, additional electrofusion fittings will need to be ordered for crossing under roads or tram and rail tracks. Similarly, the method of making the connection from the gas pipeline should be considered.

Installation work

The widest possibilities are created by saddles for drilling. They make it easier to undertake leak test and to start up the gas pipeline, due to the possibility of successive inclusion of customers and the leak test of the connection itself. The disadvantage, however, is the shift of the connection axis upwards and a significant reduction of the cover over the saddle itself. There are cases of the upper part of the saddle breaking while carrying out earthworks. These defects do not occur when using reduction tees, but as a consequence their use forces the contractor to leak test simultaneously on the entire gas pipeline. This makes it difficult to locate leaks and remove them, especially with a large number of connections.

Installation work

- During storage and transport, pipes should be plugged, especially those that are stored directly on the ground.
- One of the main operations at the construction site is cutting the pipe to the desired length. Using the right tools allows you to cut perpendicular to the axis, which can save a lot of time on subsequent assembly.

Contemporary pipeline construction technologies

Methods of pipe connection

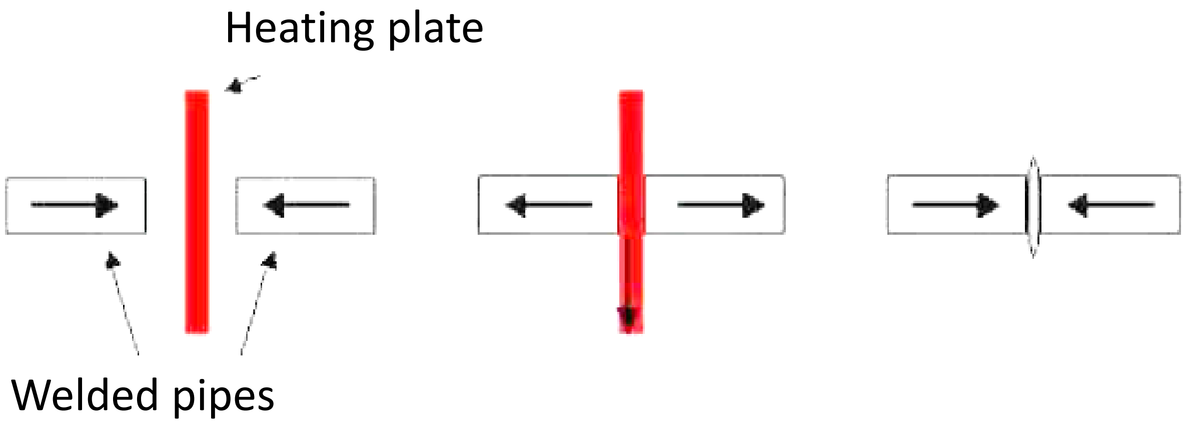
In practice, there are two methods of connecting pipes used in the construction of PE gas networks, these are:

- Butt welding
- Electrofusion welding

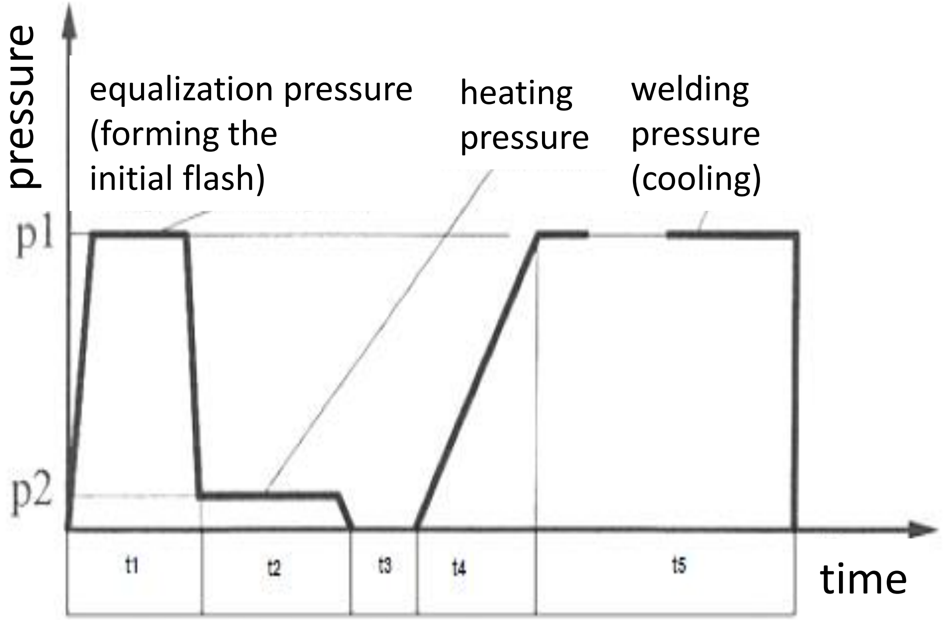
Butt welding with a hot plate

The process consists in heating and plasticizing the ends of the welded elements through the contact of their front faces with a heating plate, and then the mutual approach of the elements to each other utilizing adequate force, after the heating plate has been pulled out.

Butt welded pipes with pipes of outside diameter > 63 mm.



Butt welding program with hot plate



Duration of individual stages of the welding process

Stage I – compensation time t1 [s]
Stage II – heating time t2–10e [s]
Stage III – switching time t3 to 6 [s]
Stage IV – time of pressure increase t4–e [s]
Stage V – cooling time t5–1.5 e [min]

Welding equipment

Devices for welding pipes with diameters from 40 to 1,600 mm.

The parameter input mode: manual or automatic.

Stands equipped with a set of double mounting brackets equipped with reduction inserts, a plane, a heating plate covered with a PTFE layer, and a hydraulic power supply.

Modern devices enable the preparation of protocols and their printing.

Devices for butt welding of pipes and fittings, prefabrication of arches and T and Y fittings.

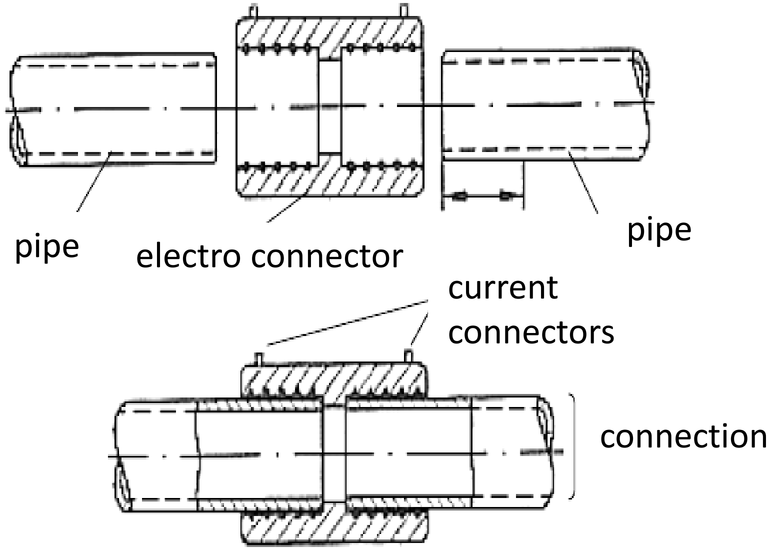
Georg Fischer machine
for butt welding

Herz welding machine
for welding T and Y fittings

Electrofusion welding

The principle of this method is the use of the heat released during the current flow through a resistance wire to heat the inner surface of the fitting and the **outer surface of the pipe**. The wire is an integral part of the fitting, and electrofusion welders are connected to supply it.

The most commonly used range of welded pipe diameters is from 16 to 200–225 mm.



Electrofusion welding

The basic parameters of welding electrofusion fittings are:

- voltage or current of power supply,
- warm-up time,
- energy,
- correction factor for ambient temperature,
- cooling time (for tightness test).

Preparation of elements for butt welding

Preparation consists in the following activities:

- clean the ends of pipes from sand, clay and other impurities,
- if it is necessary, place it under the movable roller tube,
- plug the movable end of the pipe so that the sand does not enter when sliding in,
- fix the welded ends in the welding machine's holders so that the inscriptions on the pipe are visible after the installation of the gas pipeline. Tighten the external jaws well,
- measure the resistance of pipe movement and the weld information and input this into the card,
- set the heating time. At 20^oC, 10 seconds for every millimeter of pipe wall thickness. At a different temperature, adjust the warming up time by ±1% of the base time for each degree of difference from 20^oC,
- if necessary, set the planing pressure.

Preparation of elements for electrofusion welding

Prepare the apparatus and place for welding (possibly unzip the tent or covers).

- Clean the ends of the pipes of sand, clay, etc.
- Mark the area for the squeegee or saddle.
- Mark the area with a scraper to completely remove the marker lines.
- Wipe both ends of the tubes with non-fibrous paper moistened with a suitable cleaner.
- Wipe the inside surface of the fitting.
- Mark the depth of insertion of the pipe into the fitting (half the length of the fitting).
- Depending on the system, attach the pipes with the fitting or the saddle in the holder.
- Connect the wires from the device to the connector.
- Turn on the camera device.

Preparation of elements for electrofusion welding

- Depending on the system, set and check the supply voltage of the fitting and the heating time and enter this data into the technology card.
- Turn on the heating of the fitting and control the heating process.
- After welding, turn the camera device off.
- Remove the wires.
- On the pipe, mark the authorization number, weld number, date and time of heating so that they are visible after the pipeline is installed.
- Fill out the weld card.
- Leave the fitting in the holders for a time of 1.5 minutes per 1 mm pipe wall thickness.
- The tightness test may be carried out after a time not shorter than 8 minutes for every millimeter of pipe wall thickness.

Control

- In order to control the welding parameters by the welder, as well as by the inspection services, the welder is obliged to record all the most important parameters affecting the quality of the weld. These values are entered into the weld card.
- The welder is responsible for the entries to the weld card and is obliged to complete it on an ongoing basis, as the card is an integral part of the post-implementation documentation. All disputes are resolved on the basis of entries made therein. This allows current control of assembly work by confronting weld markings on the pipe.

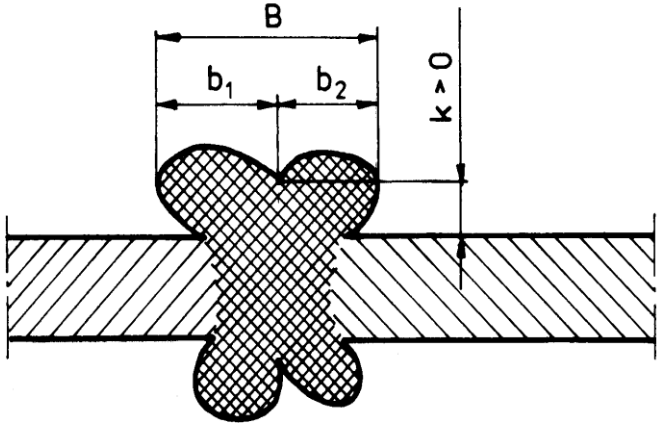
Quality documentation

- Certificates about the calibration of welder machine.
- Current welders' qualifications, materials’ and devices’ for welding certificates.
- Welders' qualifications.
- Welding supervision and inspection system.
- The necessity of control at all these stages is caused by the lack of unambiguous non--destructive methods for determining the weld quality.

Visual evaluation of butt welds

As a part of the visual assessment, a flash inspection and weld geometry measurements are made. The following is evaluated:

- the shape of the rollers (uniformity on the circumference),
- smoothness and homogeneity of the flash (no visible scratches visible to the naked eye, blisters, cracks and streaks),
- no gaps, especially in the groove between the rollers,
- permissible deviation of the axis refraction at the welding location must not be greater than 1 mm on a length of 300 mm from the joint.



Visual evaluation of butt welds

- The traces of removing (scraping) the surface layer of the pipe should be visible along the perimeter of the pipe at least 1 cm from the edge of the fitting.
- Control spouts, located in the electrofusion fitting, should be in the position provided by the manufacturer of the fitting as the position after heating the fitting.

Destructive testing

Destructive tests are most often carried out:

- when there is a reasonable suspicion of lower weld strength, caused by significant failures in the welding procedure,
- when the appearance of the flash raises doubts as to its quality, despite the sealing parameters being observed,
- in disputable matters,
- a tube section with a control weld made 2Dn from the end of the pipe is subjected to testing. The total length of test tube can not be less than 6Dn.

Destructive testing

The destructive tests include:

- measurement of immediate strength, as part of these tests:
  - ✓ static and dynamic tensile strength,
  - ✓ static (bending angle) and dynamic (impact strength) bending strength;
- measurement of long-term endurance – due to the long time of testing (from 1 to 100 hours), this type of trial is carried out in cases of dispute and for cognitive purposes, their major advantage is the measurement of real weld strength and the ability to simulate natural operating conditions (e.g. biaxial stress state). As part of these tests, tests are carried out:
  - ✓ long-lasting tensile strength (creep measurement),
  - ✓ resistance to internal pressure.

Welding equipment

Electrofusion welding devices allow you to weld pipes with a diameter of 16 to 800 mm. Depending on the device's capacity, it is possible to weld pipes to a given range of the series. For example:

- Power device: 1,200 W – max pipe diameter: 90 mm
- Power device: 1,800 W – max pipe diameter: 160 mm
- Power device: 2,200–2,500 W – max pipe diameter: 250 mm
- Power device: 3,000 W – max pipe diameter: 400 mm
- Power device: 3,500 W – max pipe diameter: 630–800 mm

The devices are produced in different versions:

- With manually adjustable sealing parameters,
- With a bar code reader (light pen or scanner), software for working with a computer.

Georg Fischer electrofusion welding machine with bar code reader

Welding equipment

The devices enable the registration of welds made (up to 4,000 welds) have an alphanumeric keypad, LCD display. In many devices there is the possibility of logging. The devices also enable automatic compensation of the welding time depending on the ambient temperature.

Output welding voltage: 8–42V

LABTRONIC ZK90ECO electrofusion welding machine. Diameters of welded pipes up to 90 mm. Manual or automatic setting

Electrofusion welder from Eurotech 800 with a bar code reader (scanner). Diameters of welded pipes up to 800 mm

Trenchless techniques

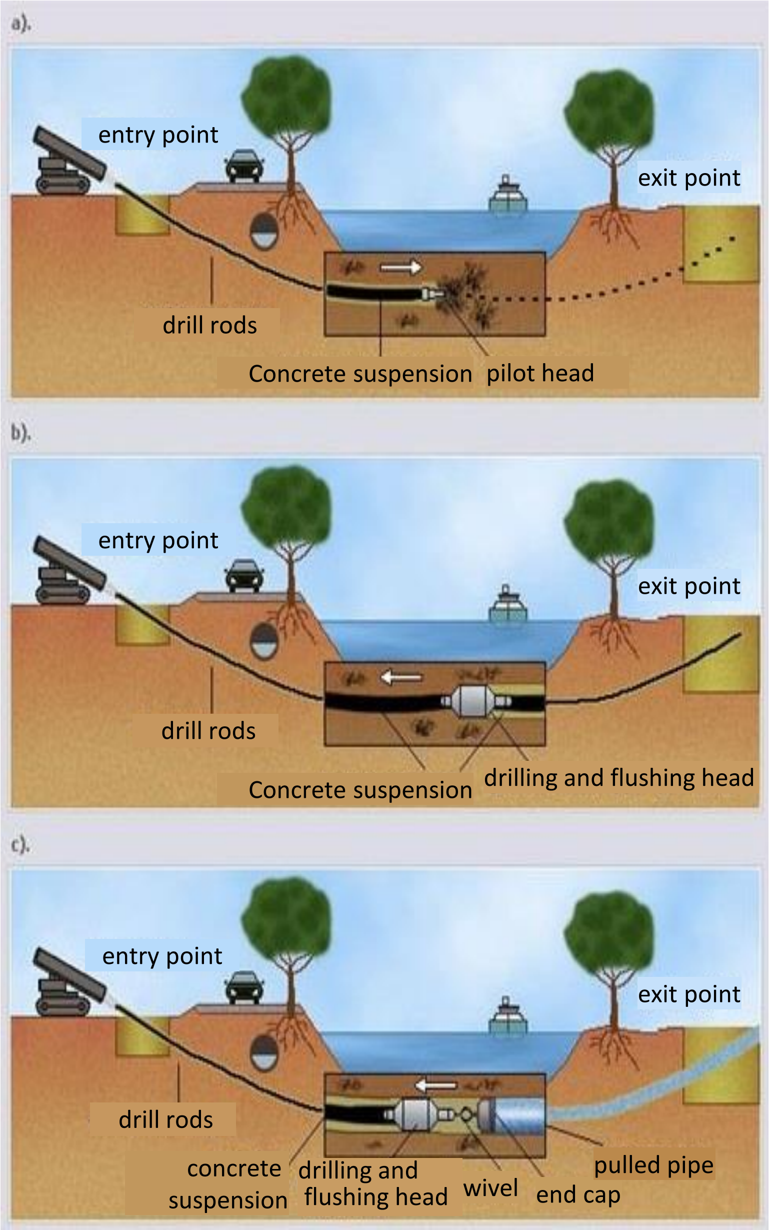
The most commonly used techniques include Horizontal Direction Drilling – a method of laying long-range underground installations that is mainly used in built-up areas and in areas with terrain obstacles; it consists in pulling and laying in the ground of the pipeline by means of drilling equipment equipped with hydraulic motors.

Construction of the pipeline by a controlled drilling method:

a) pilot drilling,

b) reaming,

c) pulling.

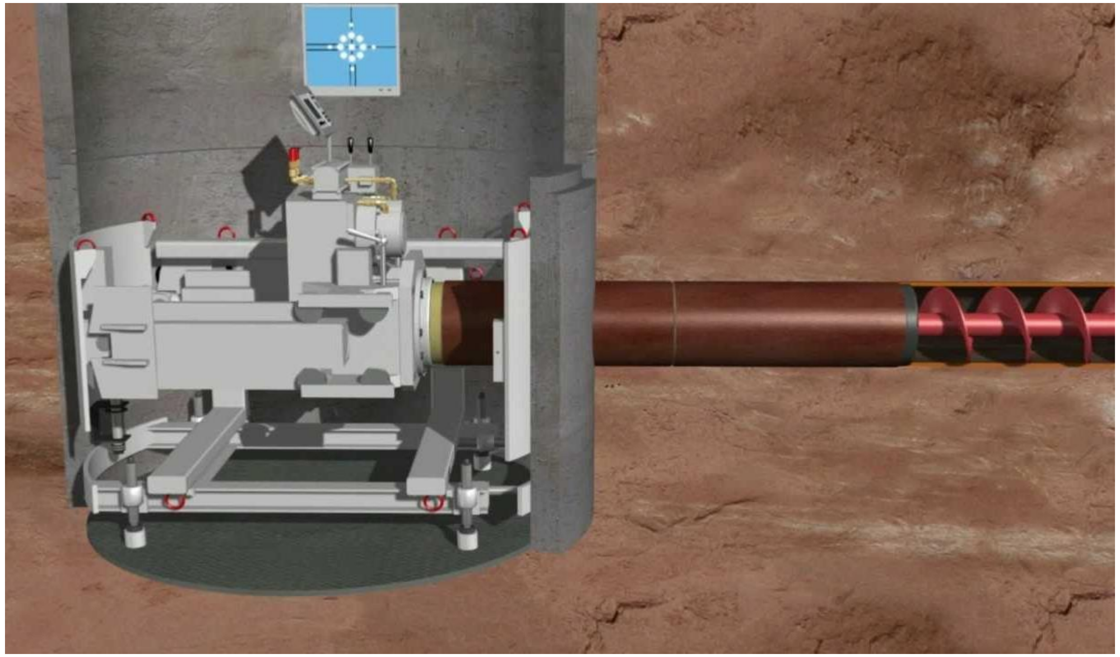


Microtunneling

- The construction of trenchless piping is completely remotely controlled from the surface by the operator using a computer system for monitoring the drilling process.
- At the beginning, a starting chamber and a receiving chamber are created – the first one must be large enough to allow the placement of the set of pushing equipment with the head, the second one must be of sufficient size to remove the head itself. Then, the micro-tunneling equipment is installed on the site, which consists of: a control container, a pipe pumping station, a lubrication system, a drilling system with pumps, a feeding device and a cutting head.

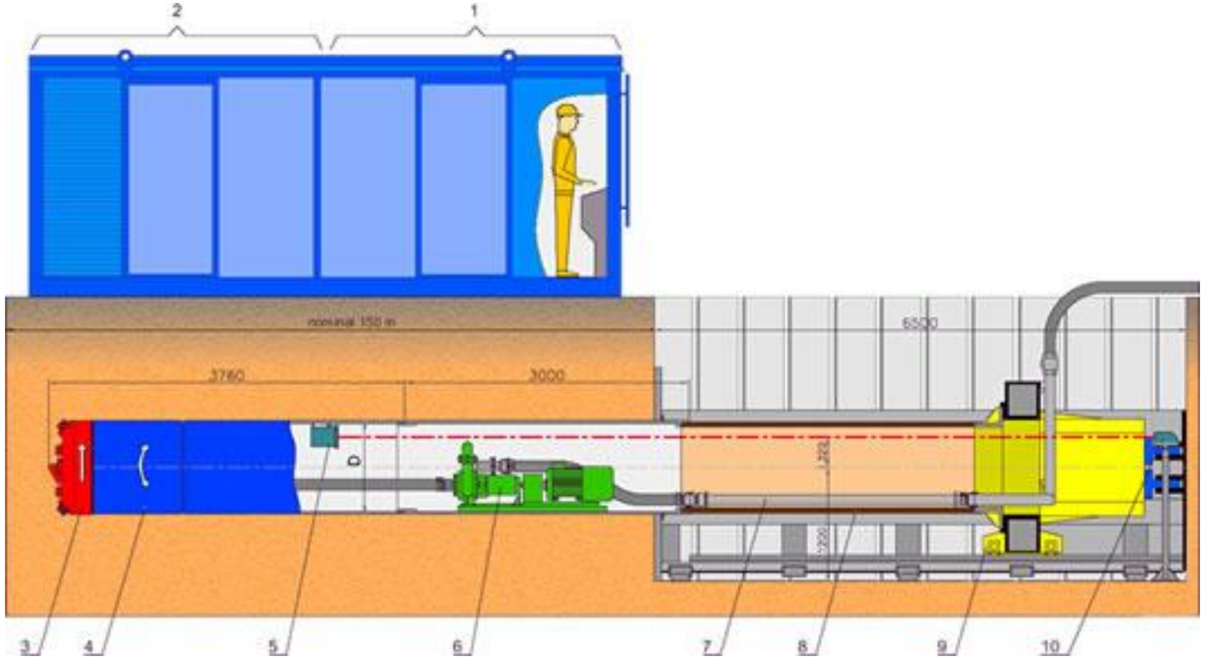
Microtunneling

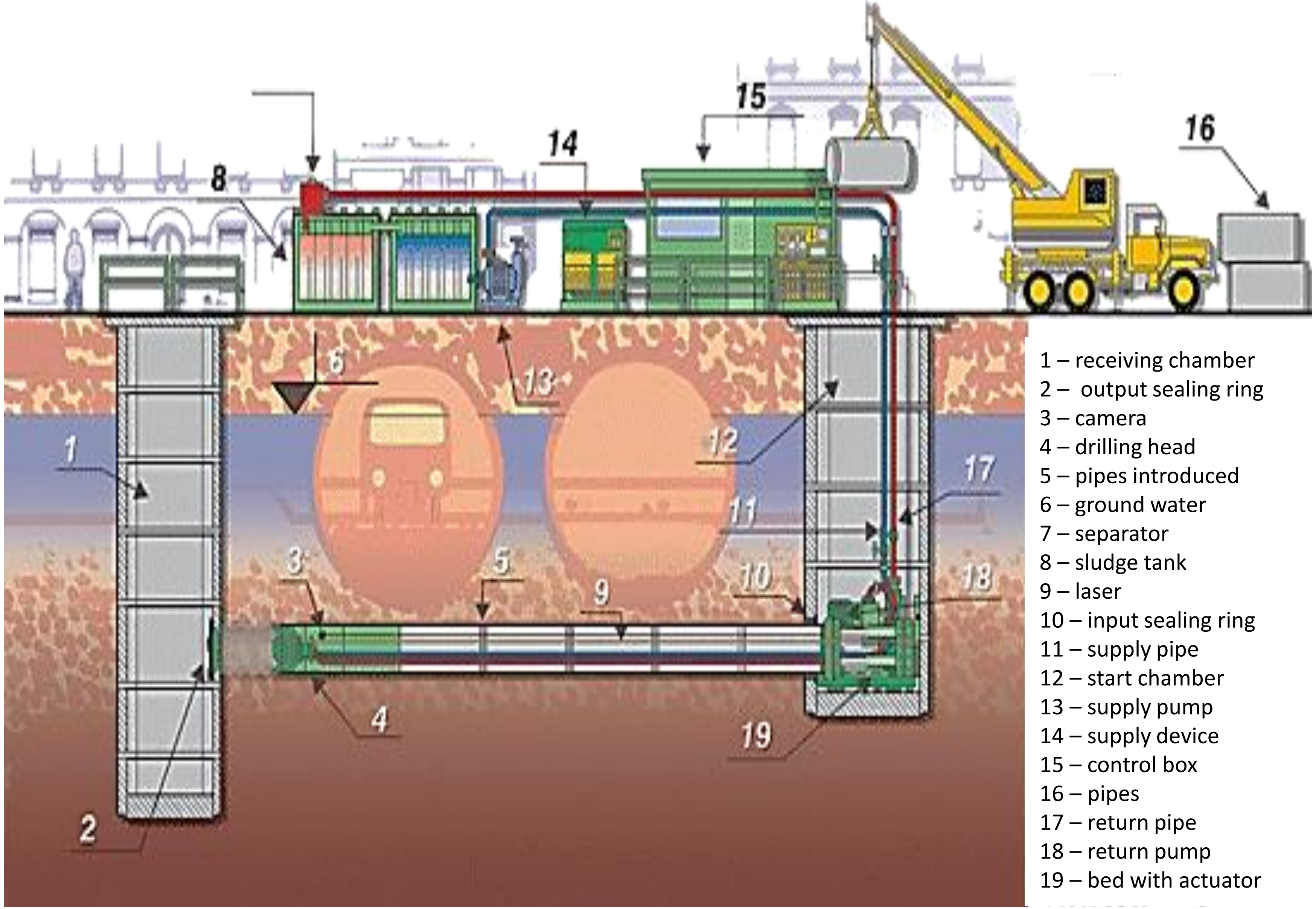
- The cutting head is pushed into the ground by hydraulic cylinders to drill the soil down to the receiving chamber. The spoil is mixed with a scrubber and transported to the surface using a duct system, where it is then segregated. The scrubbing system is also designed to balance the pressure of groundwater. The washer in the closed circuit is delivered to the head and to the surface by means of the feed and discharge pumps.



Microtunneling

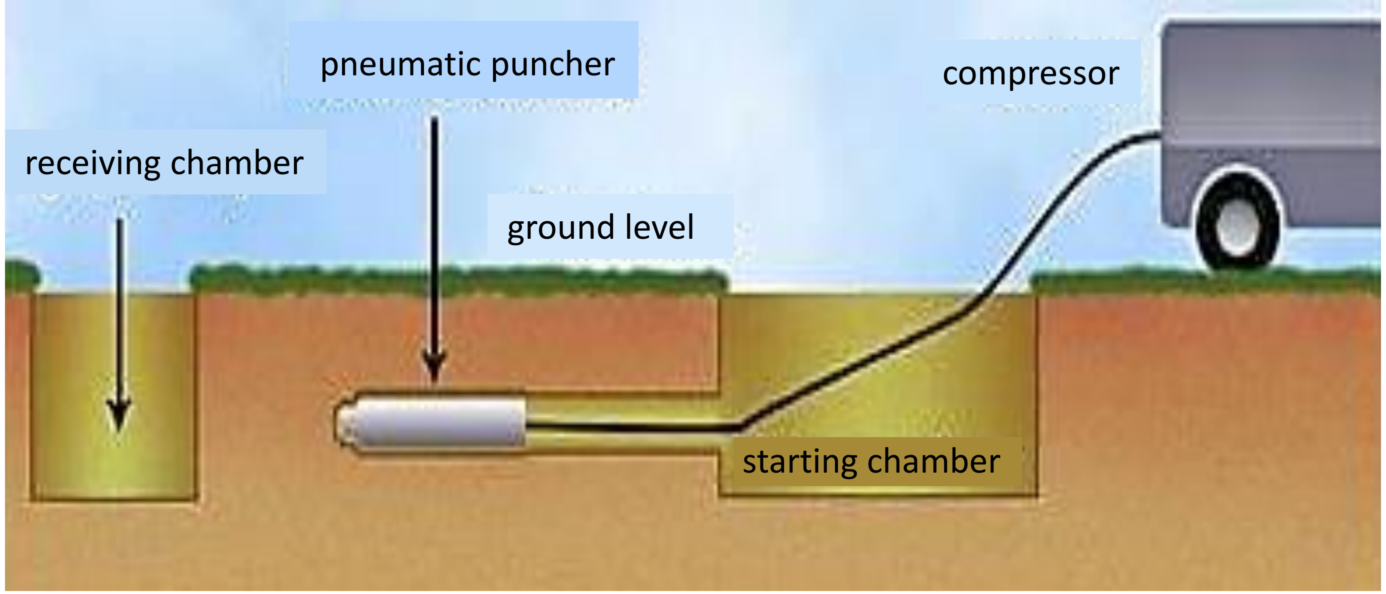
- The cutting head is pushed into the ground by hydraulic cylinders to drill the soil down to the receiving chamber. The spoil is mixed with a scrubber and transported to the surface using a duct system, where it is then segregated. The scrubbing system is also designed to balance the pressure of groundwater. The washer in the closed circuit is delivered to the head and to the surface by means of the feed and discharge pumps.



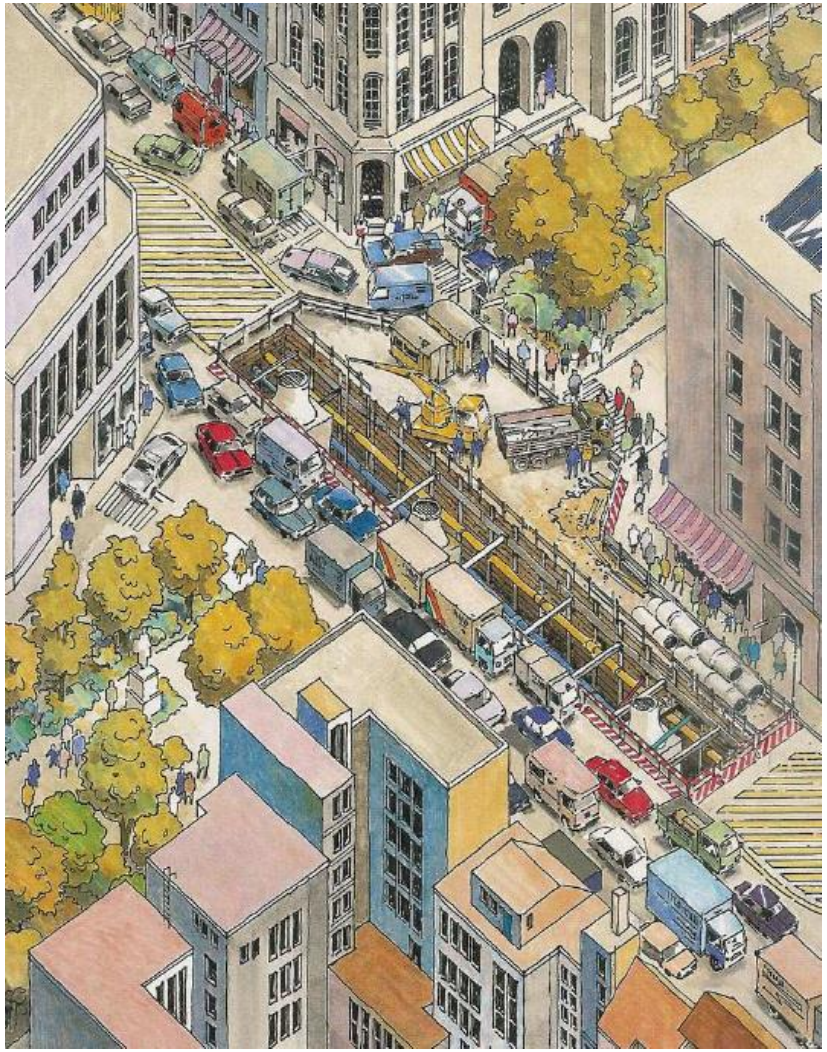


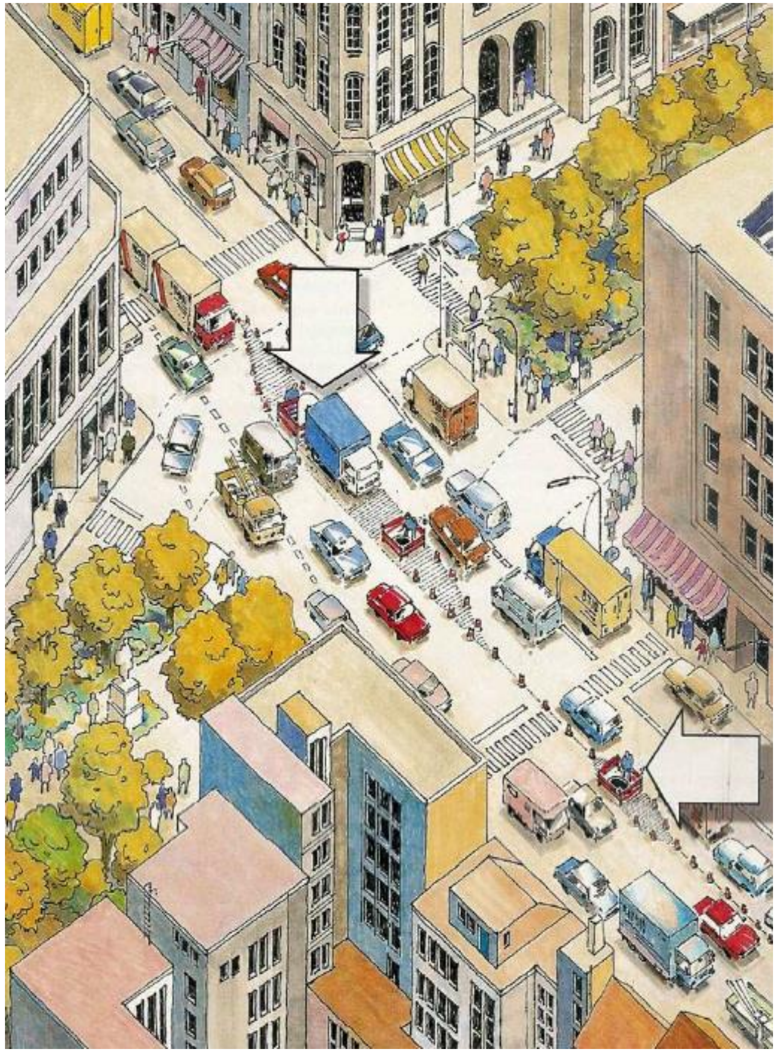
1 – receiving chamber
2 – output sealing ring
3 – camera
4 – drilling head
5 – pipes introduced
6 – ground water
7 – separator
8 – sludge tank
9 – laser
10 – input sealing ring
11 – supply pipe
12 – start chamber
13 – supply pump
14 – supply device
15 – control box
16 – pipes
17 – return pipe
18 – return pump
19 – bed with actuator

Pneumatic punches using a punch or so-called mole (Impast Moling) – this method consists in conducting through a designated section, a pneumatic punch (or mole), which simultaneously draws new pipes behind it.



Difference between excavation techniques and trenchless techniques





Exploitation of the active gas network of the PE

Exploitation = gas distribution + network development

- Natural gas in Poland has great prospects and development opportunities. The industry is constantly developing and more and more often we hear about natural gas in the media due to the discovery of large shale gas deposits in Poland. The increased share of natural gas in the energy balance of Poland may become one of the basic factors of the pro-ecological development of the regions and the country as a whole.
- In recent years, Poland has declared that it will reduce the amount of exhaust emissions and therefore, the present power plants are carrying out investments aimed at the installation of gas turbines for power generation.

Exploitation = control

In order for the gas pipeline to fulfill its **basic function** of **gas transmission**, it must meet all safety conditions throughout its entire lifetime. The lifetime of gas pipelines is now up to **100 years**. Gas pipelines are mostly underground, so we can not do visual inspections. They are located under rivers and roads and in order to find out whether the safety conditions qualifying the gas pipeline for further operation are met, it is necessary to carry out periodic surveys of the condition of the gas pipeline and many other factors affecting the gas pipeline and its immediate surroundings (zones).

Types of gas pipeline control

During operation, gas pipelines should be periodically inspected for technical condition in order to ensure work safety and continuity of gas supplies to customers.

The inspection of technical condition of gas pipelines should be based on:

- results of inspections, tests, inspections and measurements,
- number, causes and types of disturbances and failures,
- assessment of gas losses.

For making ad hoc detailed inspections of technical condition of gas pipelines we can carry out:

- route of the gas pipeline,
- examination of watercourse crossings,
- detour, network celebrations,
- measurements of pressure distribution at characteristic points of the gas pipeline (at gas stations, valve systems),
- carpet control of the tightness of the gas network.

Flight control of the pipeline

During the inspection of the gas pipeline from the air:

- check the route of the gas pipeline to detect and type potential leak points – these places are characterized by **discoloration** of the earth's surface in the form of spots or discoloration of vegetation,
- the route marking of the gas pipeline is examined,
- the general condition of the facilities is visually assessed, i.e.: fences of units and nodes, ventilation columns, cathodic protection measurement points,
- the violation of the protective zone of the gas pipeline by third parties is controlled by recording any violations thereof, such as: earthworks, construction of buildings or objects,
- the condition of the gas pipeline (leaching, landslides, etc.) is inspected – this includes ascertaining whether there is a breach of the gas pipeline cover due to its shallowing, landslides, washing up, peat or soil harvest, excavation of spoil (sand, gravel), etc.,
- the need to cut bushes in the protective zone of the gas pipeline is assessed.

Innovative control methods

- One of the innovative methods is the control of gas pipelines from the air.
- The inspection consists of an airborne (helicopter) surveillance using installed lasers and thermal imaging cameras. Herein, certain companies can be hired to assess the gas pipeline surroundings by utilizing full spectrum analyzers.

A helicopter with a thermal imaging camera

Survey of watercourse crossings

Watercourse crossing examinations are performed by a company having authorized divers and surveyors. During the inspection of each exceedance, the following shall be prepared:

- situational sketch of crossing with offsets and with the indication of the north direction,
- measurements in order to draw up a watercourse cross-section at the place of crossing, taking into account the bottom profile and the route of the gas pipeline under the bottom or the place of its exposure,
- measurements for drawing a longitudinal section of a watercourse so as to ascertain the shape of the bottom profile at the point of watercourse crossing as well as upstream and downstream of the gas pipeline, which allows predicting tendencies to trim and to exposure.

Walk control

The gas pipeline runs are carried out at a frequency depending on their classification in the 1st, 2nd or 3rd category.

- gas pipelines included in category I – not less than once a day,
- gas pipelines included in category II – not less than once a month,
- gas pipelines included in category III – no less frequently than once a quarter.

The division of gas pipelines into categories is related to the threat they pose.

Category I includes gas pipelines where gas leakage was detected to the extent that permits penetration into buildings, creating conditions that could lead to a gas explosion, as well as gas pipelines running through mining areas.

Walk control

- Category II includes gas pipelines running through undeveloped mining areas, viaducts, bridges, as well as gas pipelines running along streets with compact development or along tram tracks. This category also includes gas pipelines on which gas escapes can occur under conditions other than those specified in Category I.
- Category III includes all other gas pipelines not included in categories I and II.
- The inspection of gas pipelines by foot should be carried out on sections where it is not possible to travel the route by vehicle or to overfly it.

Walk control

Carpet control

- Carpet control of the network tightness is carried out using instruments with continuous measurement of methane content in the air. Thanks to the continuity of the measurement, the entire section of the gas pipeline is surveyed, not just its points.
- Carpet control devices have a sensitivity threshold of 1 ppm, which guarantees high measurements accuracy.
- ppm (parts per million) – a way of expressing the concentration of very diluted solutions of chemical compounds. This concentration is a derivative of the molar fraction and determines how many particles of the compound is per 1 million molecules of the solution.
- Carpet control devices fro assesing the state of the gas network can be portable or installed on vehicles, thanks to which it is possible to control large parts of the network more quickly and to constantly analyze the methane concentration and the distance traveled.

Carpet control

Leak detection through pinning

- Pinning the gas pipeline route is to determine the location of a potential leak by locating the point with the highest concentration of gaseous fuel. When pinning, one should take into account the topographical conditions, the properties of the ground on which the gas pipeline is located and its utilities (stub pipes, fittings and flange connections). A number of control holes are made in the ground. The test is carried out using a probe with a percussion piston.
- The probe is inserted to a depth of 0.4 m (up to the height of the mounted stop on the pin) and then, using a explosionmeter detector or methane detector, the methane content in the made hole is measured. This method has various applications, but it should be used with caution in the vicinity of underground infrastructure (power cables, fiber optics, etc.).

Remote control systems

Remote measurements of pressure distribution at characteristic points of the network are one of the elements of control of the technical condition of gas pipelines.

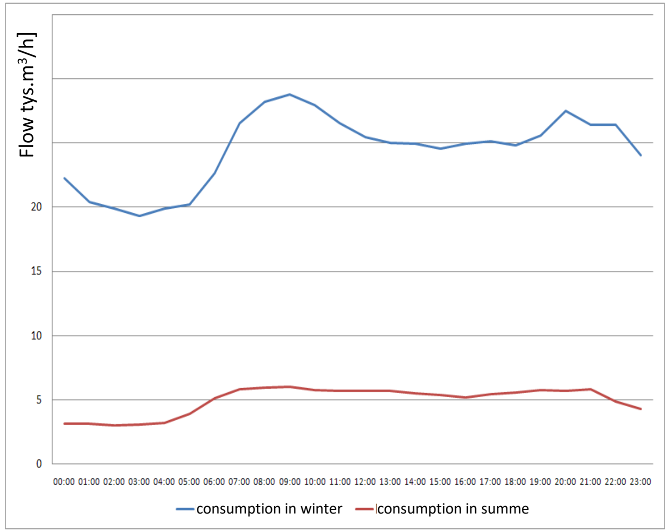
Among the data sent, are:

- inlet and outlet pressures from gas stations,
- gas flow in specific directions of transmission (calculated on the basis of: static pressure, differential pressure at the orifice or flow data from turbine gas meters, geometric parameters, temperature of the measurement system and gas composition),
- gate valves and taps needed to determine the direction of gas flow,
- pressures and suction pressures in gas compressors in compressor stations,
- gas temperature during pressing,
- measuring the amount of gas,
- the value of injection pressure to Underground Gas Storage,
- volume and flow of gas injected or transferred by Underground Gas Storage,
- gas temperature after heating on high pressure gas stations.

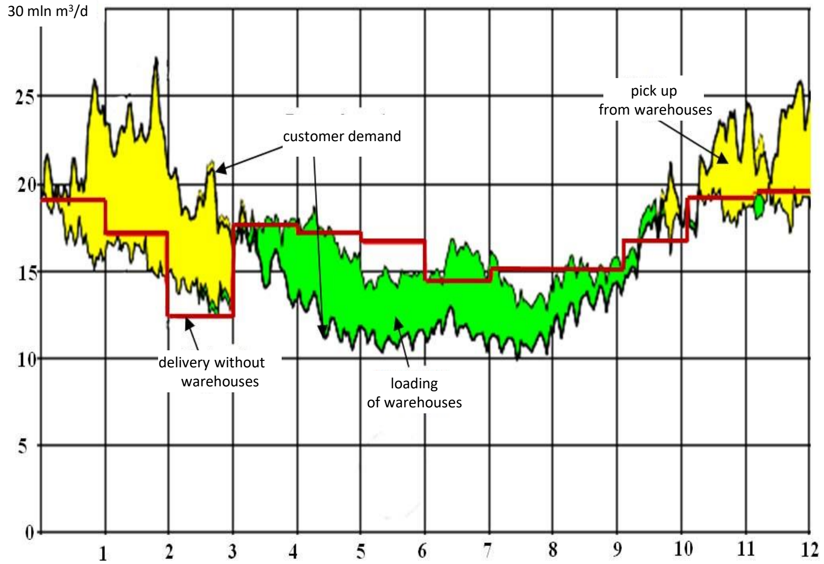
SCADA

- SCADA System – Supervisory Control & Data Acquisition Systems is a system used in industry and engineering.
- SCADA systems are applications used to monitor and control distributed systems such as, among others, gas pipelines. It is a very broad concept that includes solutions for many types of industry.
- The SCADA system has three basic elements:
  - ✓ central control room with superior computers,
  - ✓ communication infrastructure,
  - ✓ RTU – multiple Remote Terminal Units – remote controllers.
- SADA consists of computer software used to collect data from the entire controllable process inside a given industry. In this case, it is a gas network and its infrastructure. These data are sent to the central computer, where they are used to control and manage the gas network.

The operator of gas pipelines forecasts future gas consumption and orders a certain amount of gas that can not be exceeded or ordered too much, which is economically unjustified. Natural gas consumption is characterized by high variability over time. Volatility is related to the different needs of gas users. Below are examples of natural gas demand profiles that occur on gas stations supplying large urban areas.



An exemplary daily profile of the natural gas demand of a station supplying a big city in the winter and summer seasons



The seasonal variation profile of natural gas demand in the transmission system

Causes of gas pipeline leakage

The most common causes of leaks in high-pressure gas pipelines:

- external causes (activities of third parties) – 50%
- defects of construction elements – 18%
- corrosion – 15% (not applicable to PE)
- instability of foundation – 6%
- improper connection – 5%
- other reasons – 6%

Part 3

General information

Thermal system

DICTRICT HEATING SYSTEM

- **Heat source –** a set of devices used to generate heat
- **Heating network –** a system of pipes running outside heated buildings, used to transfer heat from the source to the nodes
- **Thermal knots (substations)** a set of devices for heat transfer, parameter processing, measurement and control

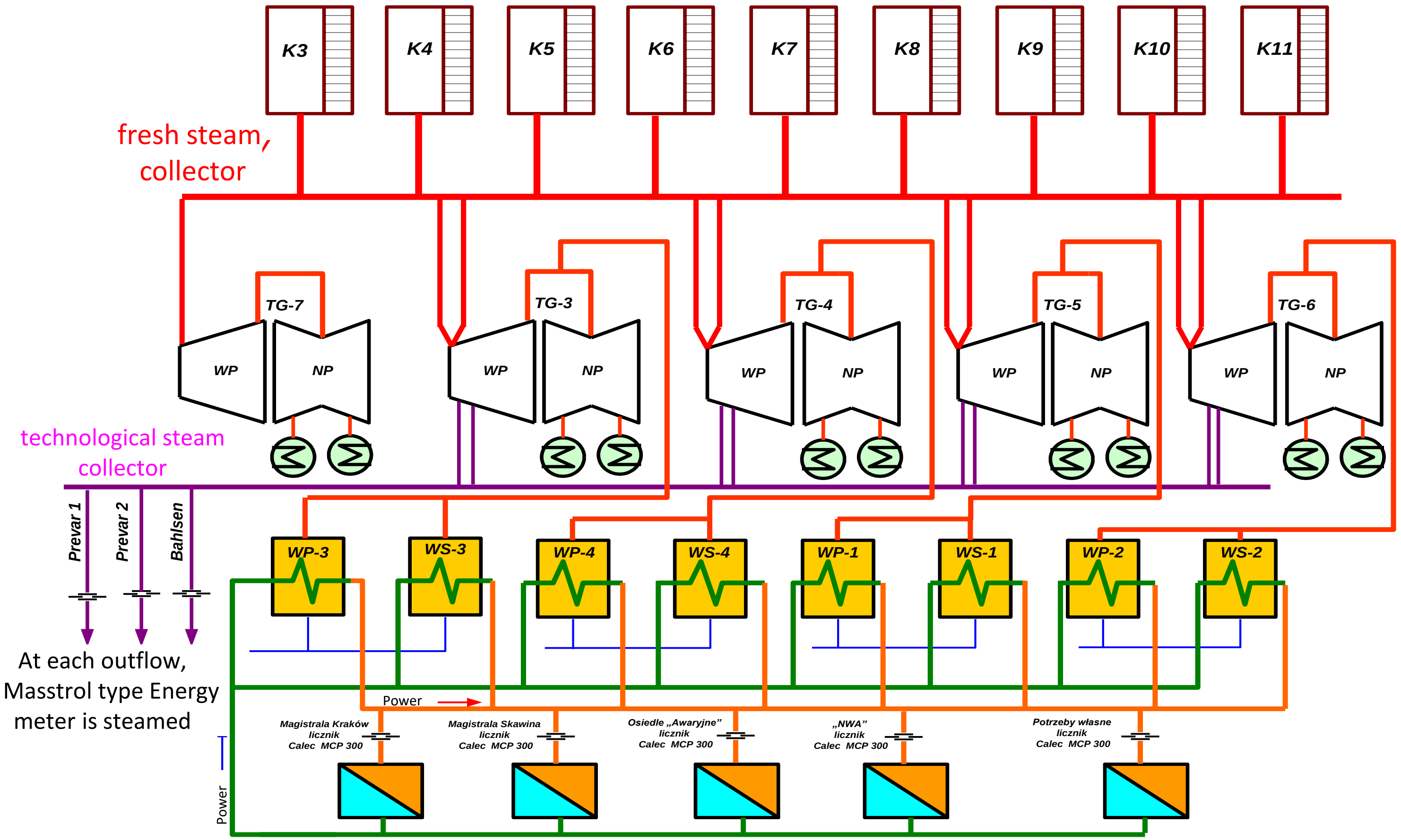
District heating network – definition

HEATING NETWORK (district heating network) – a set of technical devices for transporting heat energy from a heat source to consumers, through a heating medium (heat carrier).

Heat production

The heating plant is an industrial plant, the main task of which is the production of high temperature medium (mostly water) for the district heating network. Conventional systems (i.e. stand alone fossil-fueled boiler installations) are now rarely found. This results from the fact that much higher efficiency is obtained by producing thermal and electric energy in a combined way (combined heat and power plants).

Schematic diagram of the Skawina heat and power plant



At each outflow,
a Masstrol type Energy
meter is steamed

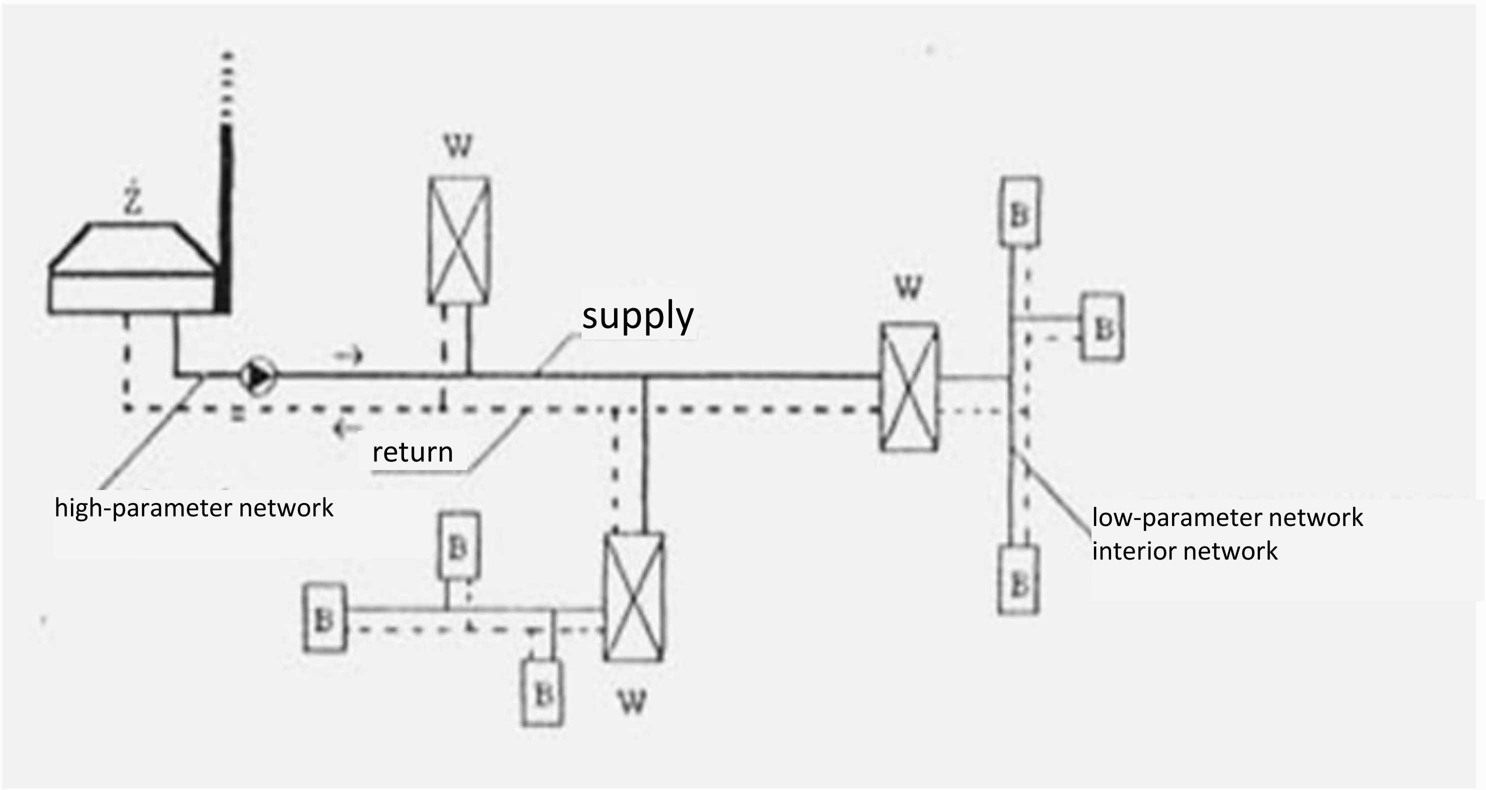
Heating system

For a heating system, a heat source may be a **heating plant**, working for the needs of many buildings or a power-heating plant. The heating plant is usually a free-standing facility with devices for generating heat with installed capacity from 10 to 15 MW.

A smaller source is the built-in **boiler house**, located in a specially separated room in the building. Such a source with a capacity of up to 2 MW may also supply more than one building with the use of an external district heating network.

The source of heat for municipal heating systems can also be combined heat and power plants or industrial heating plants.

Diagram of heating network



Heating network

In municipal heating networks, the most commonly used carrier is water. In low parameter networks, the water temperature does not exceed 115°C.

Such parameters are used in local (eg. district) heating systems. In high-parameter water municipal networks covering the whole city, the heating medium temperature does not exceed 135°C.

Industrial mixed-heating heating systems very often use steam as an energy carrier. If the vapor pressure in the heating network exceeds 70 kPa (overpressure), then such a system should be classified as high-parameter (high pressure).

Substations

Substations usually supply the building with heat. Sometimes there are even several substations in one building, constituting a source of heat for installations such as heating, domestic hot water installations, ventilation and air conditioning systems in repeated parts of the building.

In this case, the substation is a boundary element between the district heating network and the building's internal installation.

Sometimes so-called group substations, constitute the energy consumption system included in the high parameter factor (from the high parameter network) and processing it to the level of the factor circulating in the low parameter network. Here, the group heat substation separates two types of heating networks.

Heat production

A combined heat and power plant is an industrial plant that generates electricity and heat in a single technological process in the form of a medium (most often water) with a high temperature, for a district heating network or industry.

Thermal power plants are most often conventional thermal power plants with extraction--condensing turbines and venting-backpressure turbines. Turbines of both types are equipped with heating exhausts, from which superheated steam feeds heat exchangers, transferring heat to the network water supplied to the central heating (c.o.) as well as for domestic hot water (c.w.u) production.

Heat production

Recently, combined heat and power plants with **gas turbines** have become increasingly popular. Also, smaller-capacity **cogeneration** plants with classic gas piston engines or diesel engines are being built. An alternative to the heat and power plant are the so-called cogeneration with the use of Stirling engines.

Combined heat and power generation is much more efficient than separate production, but the high cost of building a heating network limits the use of centralized heating to **densely populated areas**. This system has many advantages because it reduces fuel consumption – emits less fumes than separately built boiler room and condensing power plant. The reason is the use of heat, which in the condensation power plant is lost to the environment (heat of condensation of water vapor).

Division of heating networks

Division due to:

- Heating medium:
  - ✓ steam (industrial facilities),
  - ✓ water (residential and public buildings),
- Medium parameters:
  - ✓ low parameter/low pressure (water temperature up to t = 115°C, steam pressure up to p = 70 kPa),
  - ✓ high temperature (water temperature above 115°C, vapor pressure above p = 70 kPa),
- Number of pipes:
  - ✓ Single-pipe (very rare case),
  - ✓ Two-pipe,
  - ✓ Three-pipe,
  - ✓ Four-pipe,
- Due to purpose of the network:
  - ✓ industrial,
  - ✓ municipal (municipal or housing),
  - ✓ mixed (industrial-municipal).

Division of heating networks

Division due to:

- Way of connecting the source and receivers (geometric layout)
  - ✓ Spider,
  - ✓ Radial,
  - ✓ Ring,
  - ✓ distribution (estate) when there is a group node from which the factor with reduced parameters supplies several buildings.
- Construction:
  - ✓ underground – once: canal,
  - ✓ ductless (in the protective tube laid directly in the ground, "pre-insulated"),
  - ✓ overhead – on low supports (50–70 cm above the ground), they are covered with greenery, sometimes hidden on high supports to bypass bridges, etc. (Google maps).

Heat transmission

There are two ways of transmitting heat at a distance:

- from centrally located heat sources, from which heat is sent over the longest possible distances,
- from local heating networks, installed, for example, in a production plant, a housing estate or a residential building.

Range

Economically justified ranges are:

- 5–10 km – hot water transmission,
- 2–3 km – transmission of steam at a pressure of 0.4–1.2 MPa,
- about 1 km – transmission of water vapor with a pressure up to 0.2 MPa.

Designing

Stages of the district network design:

- technical and economic studies,
- conceptual design,
- preliminary project.

Stages of local network design:

- determination of heat demand for heating,
- technology and social purposes.

Heat carriers

The heat carriers are liquid or gaseous substances.
Their task is:

- **Collection** (storage) of heat in its source, transport and putting it in the receiver (heating media),
- **Heat transfer** in a refrigeration system, transport of a cooled carrier and e.g. cooling of products in technological devices (heated media).

Heating media

Requirements for heating media:

- high enthalpy (the so-called heat content) in the heated state,
- low energy losses for transport,
- harmlessness and non-aggressiveness for man, pipes and the environment,
- low cost and availability.

Heating media

The most commonly used heating media carriers include:

- steam,
- water
- liquids with elevated boiling point,
- exhaust fumes or hot gases,
- air.

Steam

Steam as a heat carrier is sometimes used, although in municipal systems water is the most commonly used heat carrier.

Steam

Advantages:

- the possibility of simultaneous use for technological and heating purposes,
- low density and therefore a small increase in the weight of pipelines filled with steam, in relation to the mass of empty pipelines, i.e. filled with air,
- low "hydrostatic" pressure, thanks to which it is not necessary to provide additional work for the purpose of feeding it to cause the flow in the heat network of the steam, as the stream of energy supplied to the steam in the steam boiler is sufficient,
- easy regulation of flow in the heating network due to automatic steam flow; this regulation consists in the proper opening or closing of steam valves,
- simple operation of the heating network, because it is easy to find and remove damage, among other reasons, because the amount of condensate formed from condensed water vapor is small and there is no problem with its discharge,
- constant temperature in the range of the dryness level $0 < x < l$ and the dependence of this temperature on the vapor pressure; this property is very advantageous when there is a need to maintain a constant temperature in the technological process, e.g. in the rectification.

Steam

Disadvantages:

- low density, and therefore the need to use steam pipes with large diameters, which is associated with the high cost of pipelines and insulating materials,
- increased heat loss to the environment (especially when the temperature of the steam is particularly high); for economic reasons, steam is a preferred factor for transmitting thermal power over short distances,
- the necessity of using in the steam network devices for dewatering of steam pipes and for condensate management, which is the cause of a more complicated and expensive construction of steam and heat networks, as well as the reason of difficulties in network operation,
- basically, there is no possibility to control the temperature of the steam, the regulation of the output power occurs only by changing the steam flow.

The use of steam for space heating is, therefore, an inappropriate solution, except for using it for heating large and intensively cooled rooms, such as production halls, where no thermal equipment is installed.

Water

Water, as a heat carrier, is used in municipal heating systems, supplying buildings with heating energy and for preparing domestic hot water.

The advantages of water as a heat carrier are as follows:

- easy, centralized (in the heat source and in the heat knot) temperature control of the carrier, so the thermal power to the current demand can be easily adjusted,
- simple construction of networks and heat knots,
- high density of water, compared to steam, allows the use of pipelines with smaller diameters, and thus to reduce the cost of building a heating network,
- low heat losses to the environment, which in a properly constructed heating network cause a small drop in the temperature of water as a carrier (about 1 K/km); which is not an obstacle for heat transfer over long distances.

Water – advantages

Water, as a heat carrier, is most often used for space heating and, to a lesser extent, for technological purposes.

The advantages of water as a heat carrier are as follows:

- high value of specific heat c = 4,190 J/(kg K),
- relatively high coefficient of heat transfer.

Water – disadvantages

The disadvantage of water as a heat carrier is associated with its high density, and other properties that cause:

- occurrence of significant hydrostatic pressure in networks located in the area of strongly varied altitude,
- significant increase in the mass of the water network pipeline after filling it with the factor, and hence the need to meet a number of strength conditions during network construction, and, increase costs,
- the need to provide elevated water pressure due to the prevention of water evaporation and due to overcoming the flow resistance, which is associated with the need to install large circulation pumps driven by electric motors.

Determination of heat carrier parameters for heating purposes

- The carrier should be sent from a heat source or heat station with a fixed pressure, which allows to overcome differences in height and resistances of the heating network.
- At the highest point of the heating network there should be a slight overpressure of the heat carrier that does not allow its evaporation.
- The medium temperature should be variable and adjusted to the current needs – quality control.
- In order to determine the required pressures in the heating network, a diagram of these pressures should be drawn up. These piezometric diagrams are necessary in the design phase of the district heating network.

Thermal network systems – configurations

Content

- Types of heating network layout,
- Criteria for selecting the correct shape of a heat network,
- Diagrams of selected network systems (one-, two-, three- and four-pipe),
- Principles of laying out water and steam thermal networks.

Configurations of networks

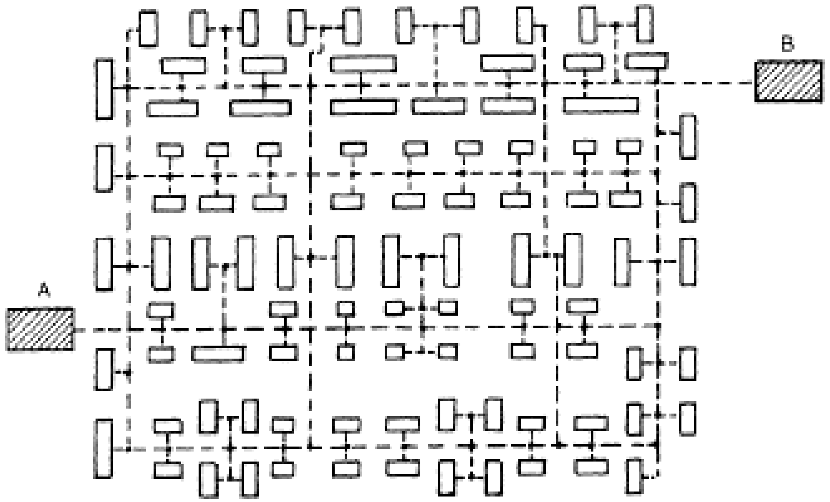
To ensure efficient heat transfer to each recipient, heat networks are built to give them shape of:

- truss,
- annular,
- radial,
- spider web (a variety of radial-shaped network),
- mixed.

Configuration of Warsaw network

Thermal network in the form of a truss

- power from two sources
- network layout compatible with the street layout
- heat supply guarantee in the event of failure of one of the sources or damage to the network section



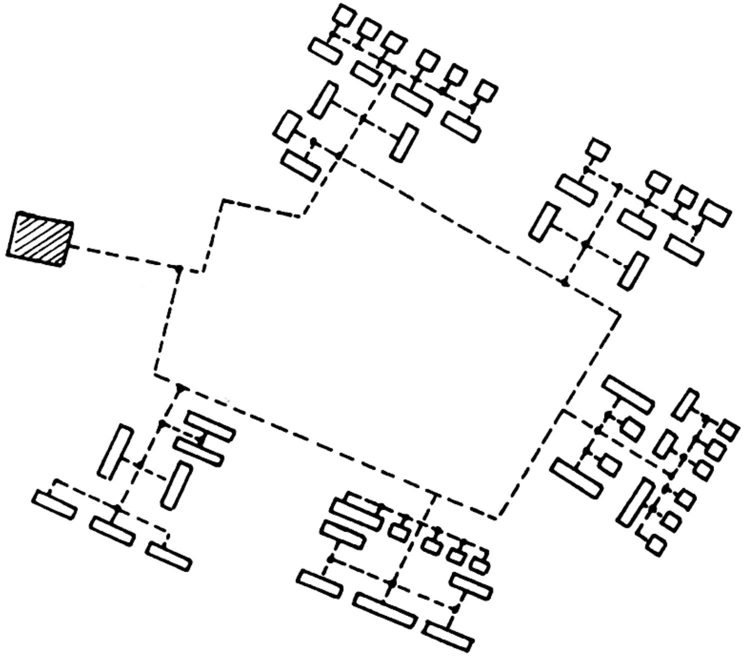
▨ – power plant

▭ – heated buildings

- - - - heating network

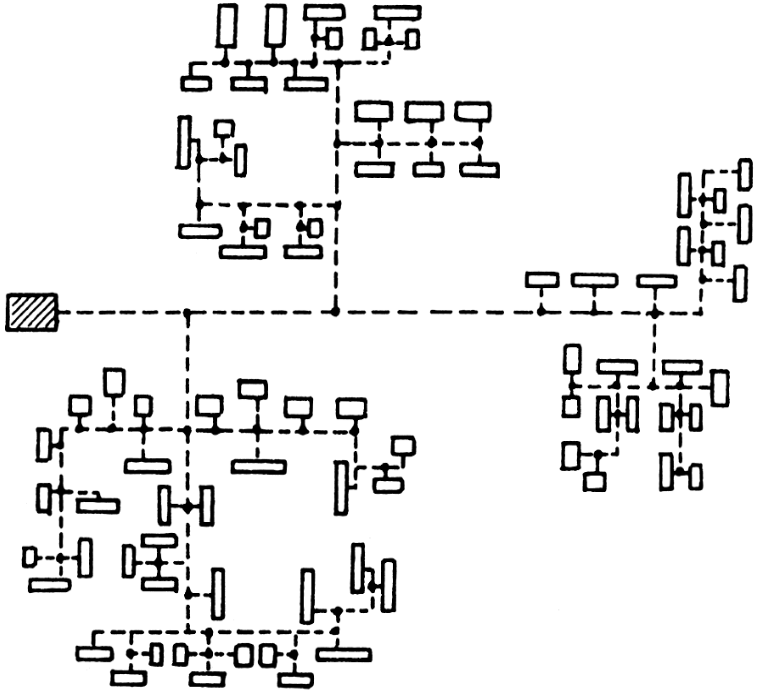
Thermal network of rings

- power supply from one source of heat
- heat delivery guarantee in case of section failure due to the possibility of two-way heat transfer



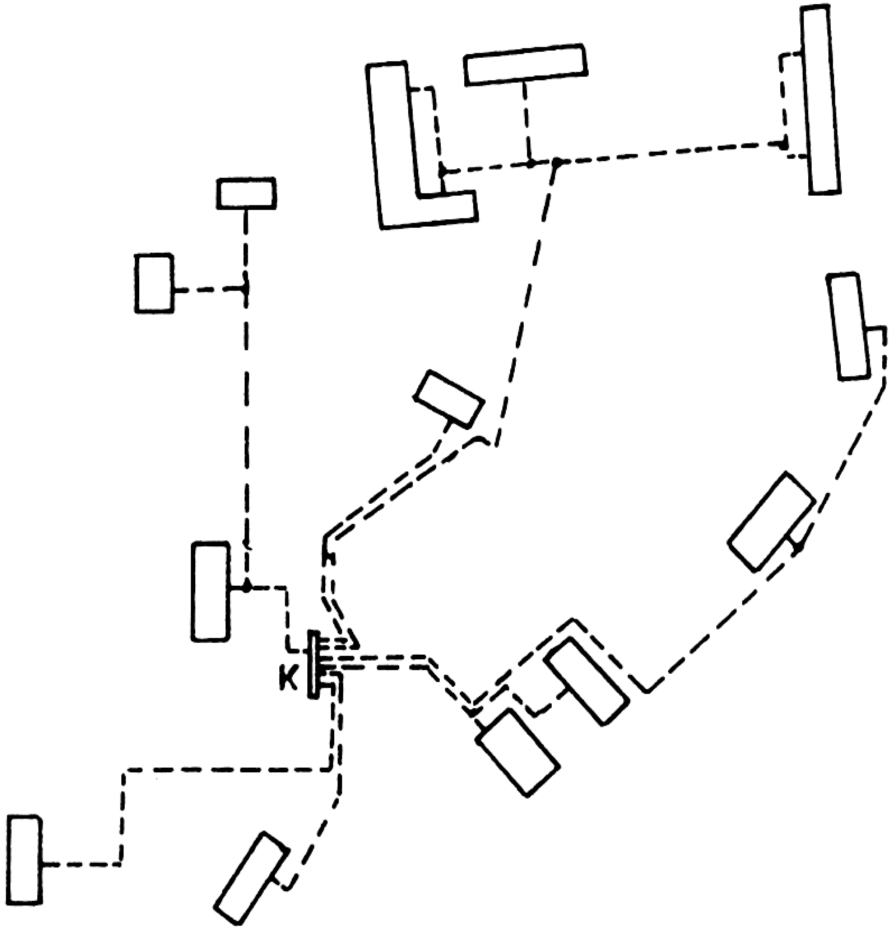
Thermal radiant network

- one source of heat
- in the event of a failure of the heating network system, there is a great threat to the security of heat supply to consumers



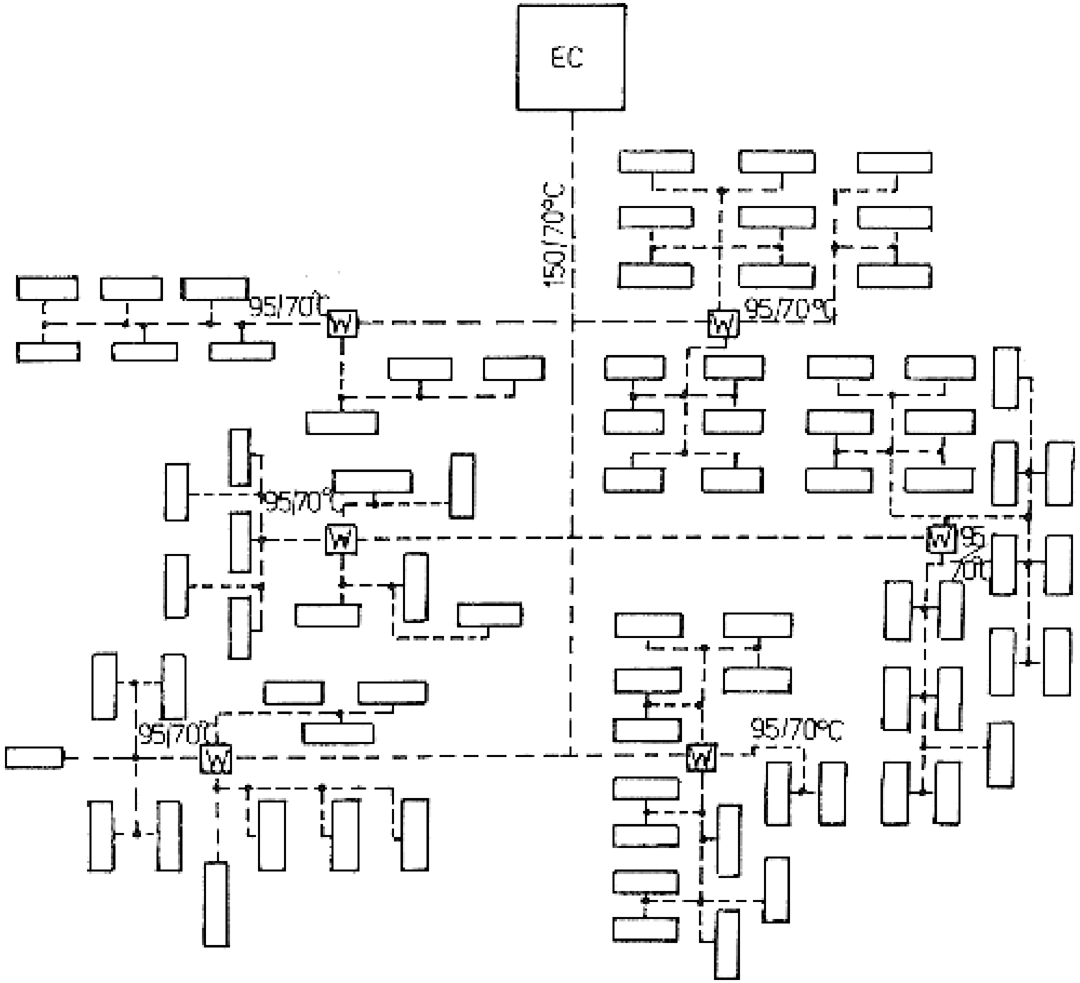
Thermal network of spider web

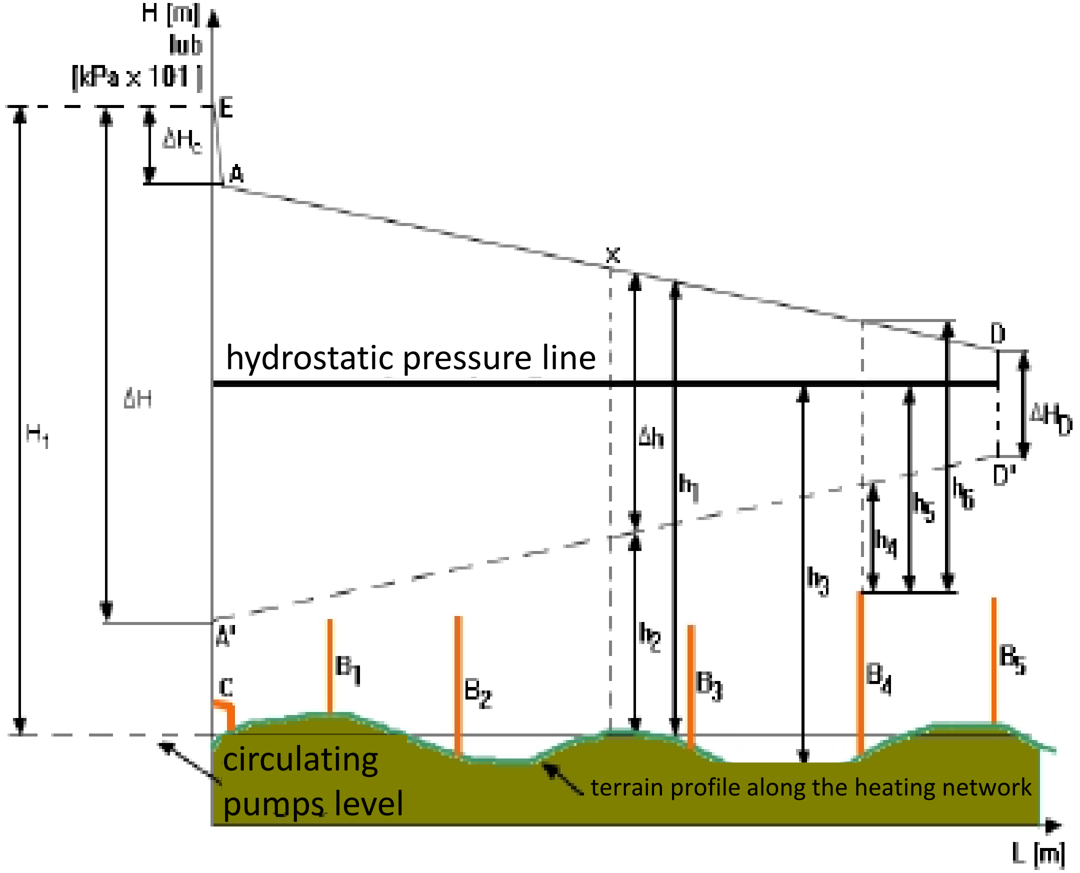
- one source of heat
- in the event of a heating network failure, heat supply is only threatened to consumers from the damaged “thread” of the network



K – collector

Heating water network transfer – distribution with group heat knots

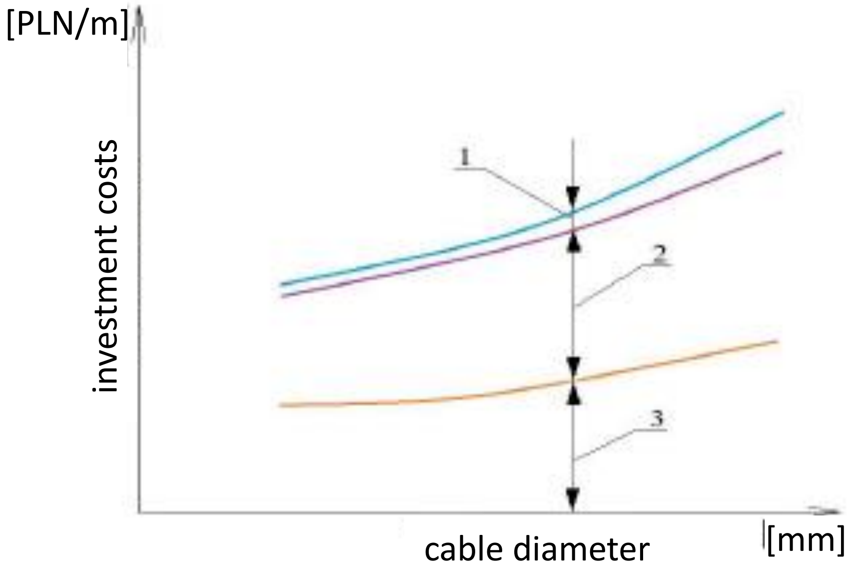




Principles of construction of piezometric diagram: A–D – pressure line in supply pipe, A’–D’ – pressure line in return pipe, A’ – pressure before the pump, E – pressure behind the pump, C – power plant, B_1–B_2 – the heights of the highest located receivers in buildings, ΔH_c – pressure drop in the power plant, ΔH – pressure rise in the pump, H_t pressure of the circulating pump, h_1 – pressure in in the X point of supply pipe, h_2 pressure in the X point of return pipe, $\Delta h = h_1 – h_2$ exposure pressure of the point H of the thermal network, hs – static pressure against the terrain, h_4, h_5, h_6 – the heighs of the network referred to the highest installation in building B_4

Function of investment costs and pipe diameter.

1 – insulation cost, 2 – pipe cost,
3 – canal cost



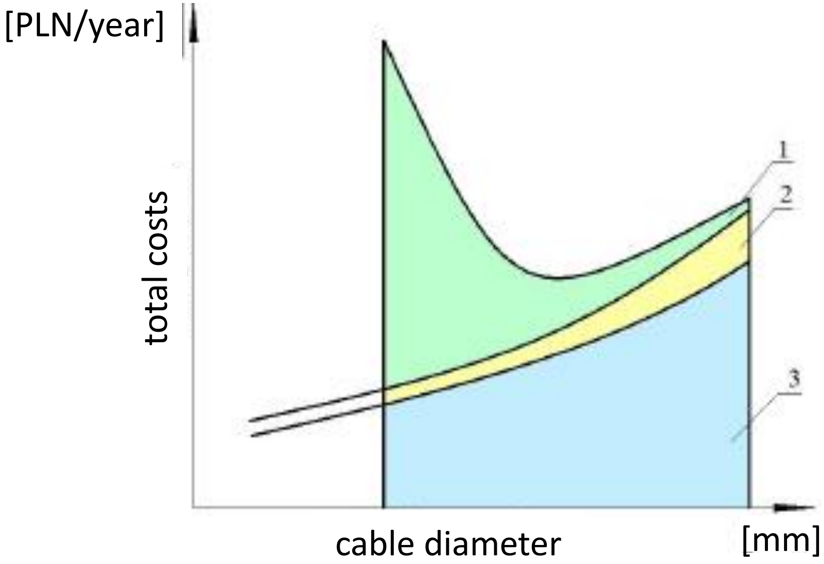
$$k_i = k_m l \frac{p}{100}$$

K_m – cost of 1 m of the pipe together with extra costs [pln/m]
l – lenght of the pipe
p – depreciation rate [%/year]

Source: Górecki, 1997

Total cost of heat distribution as a function of pipe diameter.

1 – pumping cost, 2 – heat loss cost,
3 – depreciation cost



Volumetric flow resulting from heat demand and enthalpy drop

$$q_v = \frac{\dot{Q}}{\Delta i}$$

$\dot{Q}$ – heat flow [W]
Δi – specific enthalpy drop of the medium [kJ/m^3]

Source: Górecki, 1997

Usefull equations

Pipe diameter, [m]

$$d = \sqrt{\frac{4q_v}{\pi w}}$$

Actual medium velocity, [m/s]

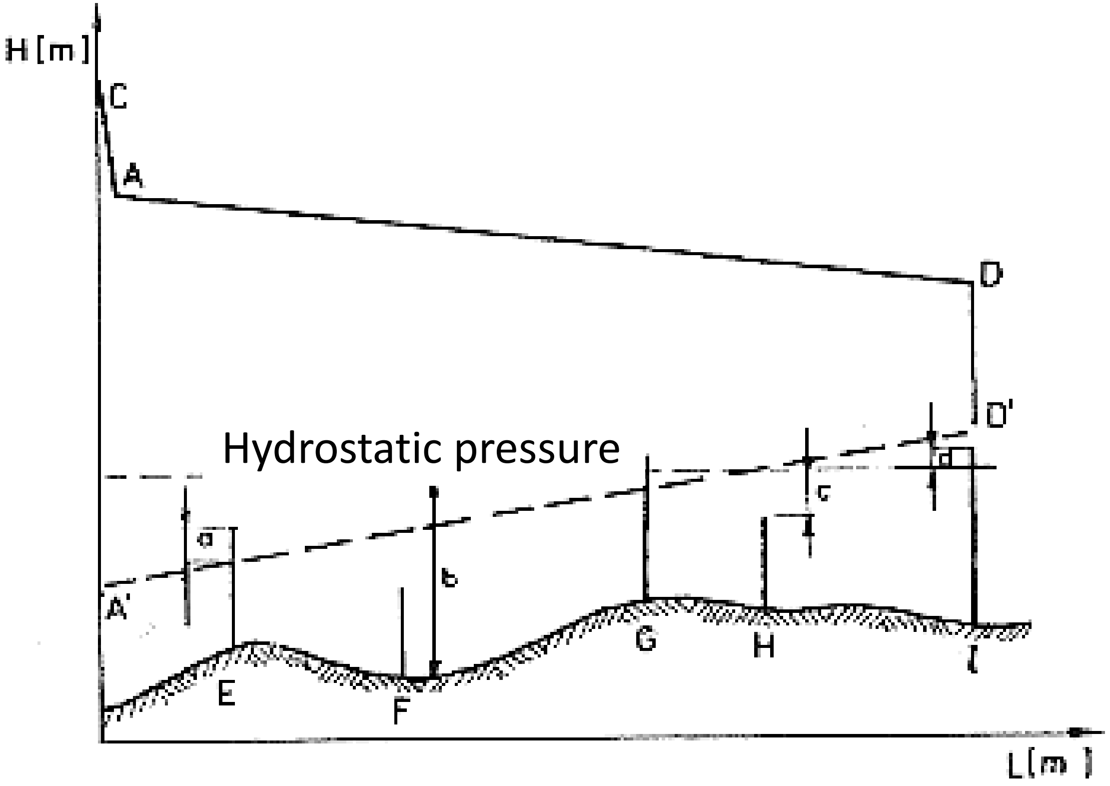
$$w = \sqrt{\frac{4q_v}{\pi d^2} = \frac{q_m}{F\rho_{śr}}} = 1{,}27\frac{q_v}{d^2} = 1{,}27\frac{q_m}{d^2\rho_{śr}}$$

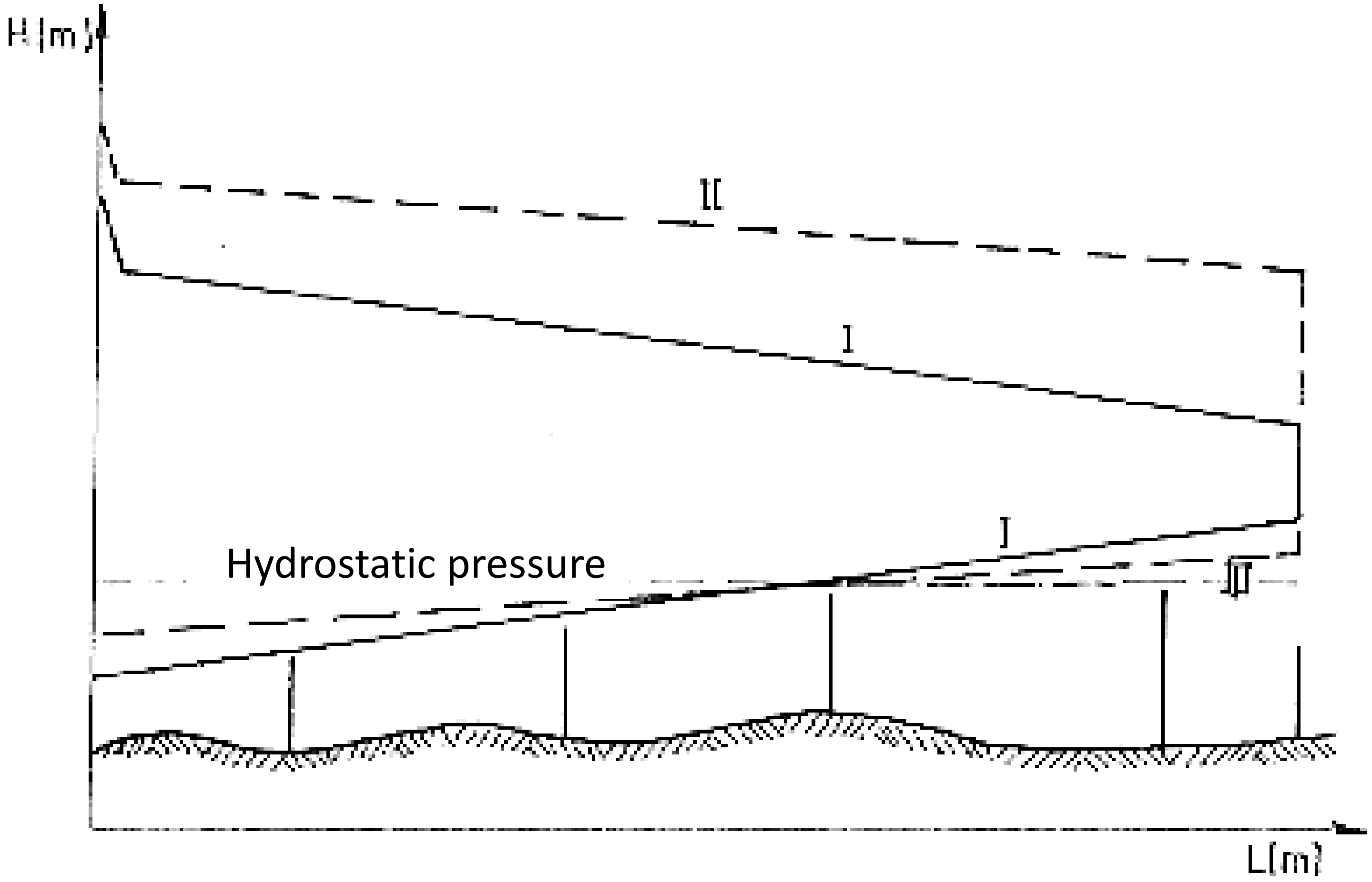
q_m – mass flow of medium, [kg/s]
$\rho_{śr}$ – average density of medium [kg/m^3]

Medium velocity in pipelines

Medium type	Pipeline type	Velocity [m/s]
Overheated water vapour	main pipeline branch	40–70 30–40
Saturated water vapour	main pipeline branch	30–40 20–30
Water vapour	overpressured of 0.1 MPa	30–60
Supply water	discharge line suction line	1.2–2.5 0.3–0.8
Cooling water	discharge line suction line	1.0–2.0 0.7–1.5
Condensate	–	1.0–2.0
Gas	overpressured 0.2 MPa overpressured 0.5 MPa long distance pipeline	5–20 10–35 25–65
Compressed air	discharge line suction line	20–30 12–20
Oil	supply return	0.8–1.2 0.2–0.3

Ways of connecting buildings to the district heating network depending on the pressure at the point of their connection

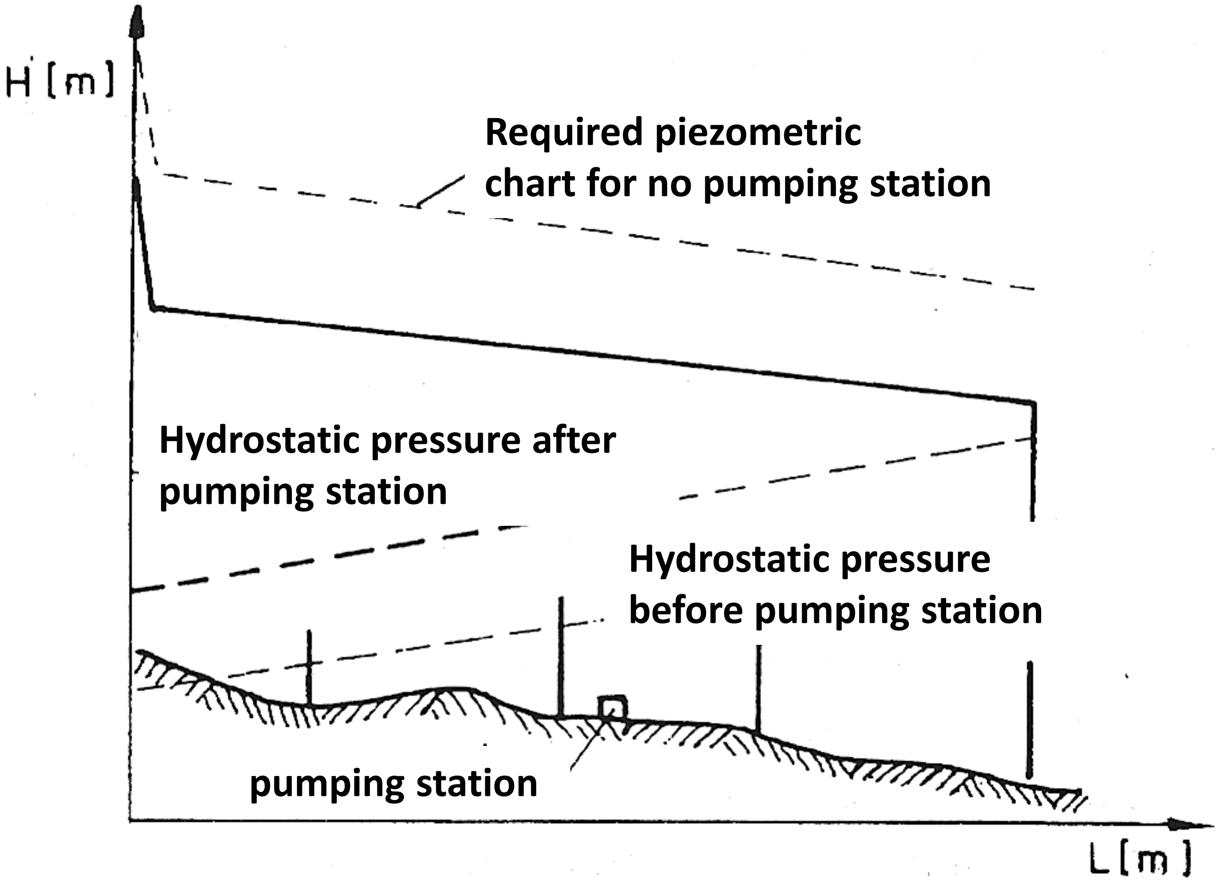




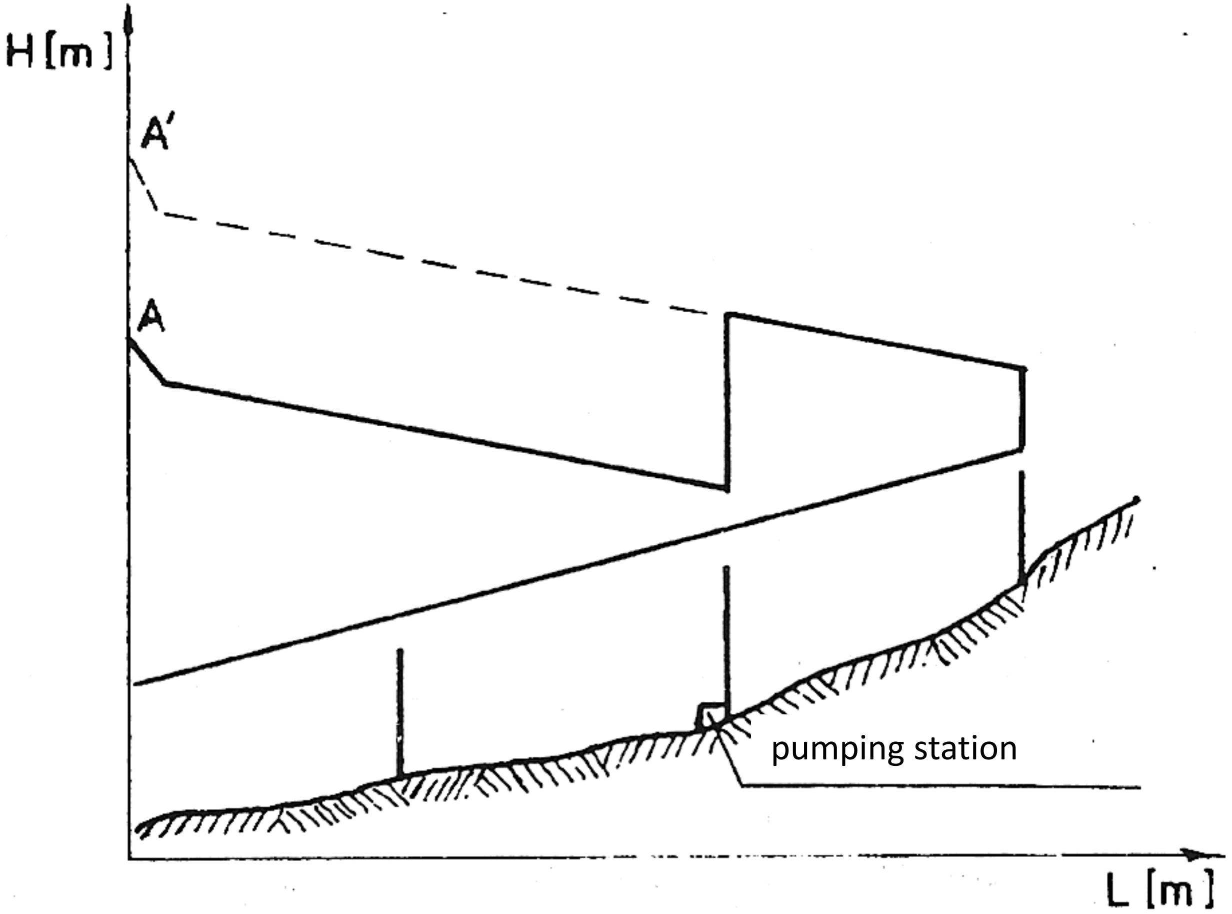
Piezometric chart for different network load

I – full load, II – transient load, III – transient load for the full load pressure

Piezometric graph for a heat network with a pumping station in the return lines

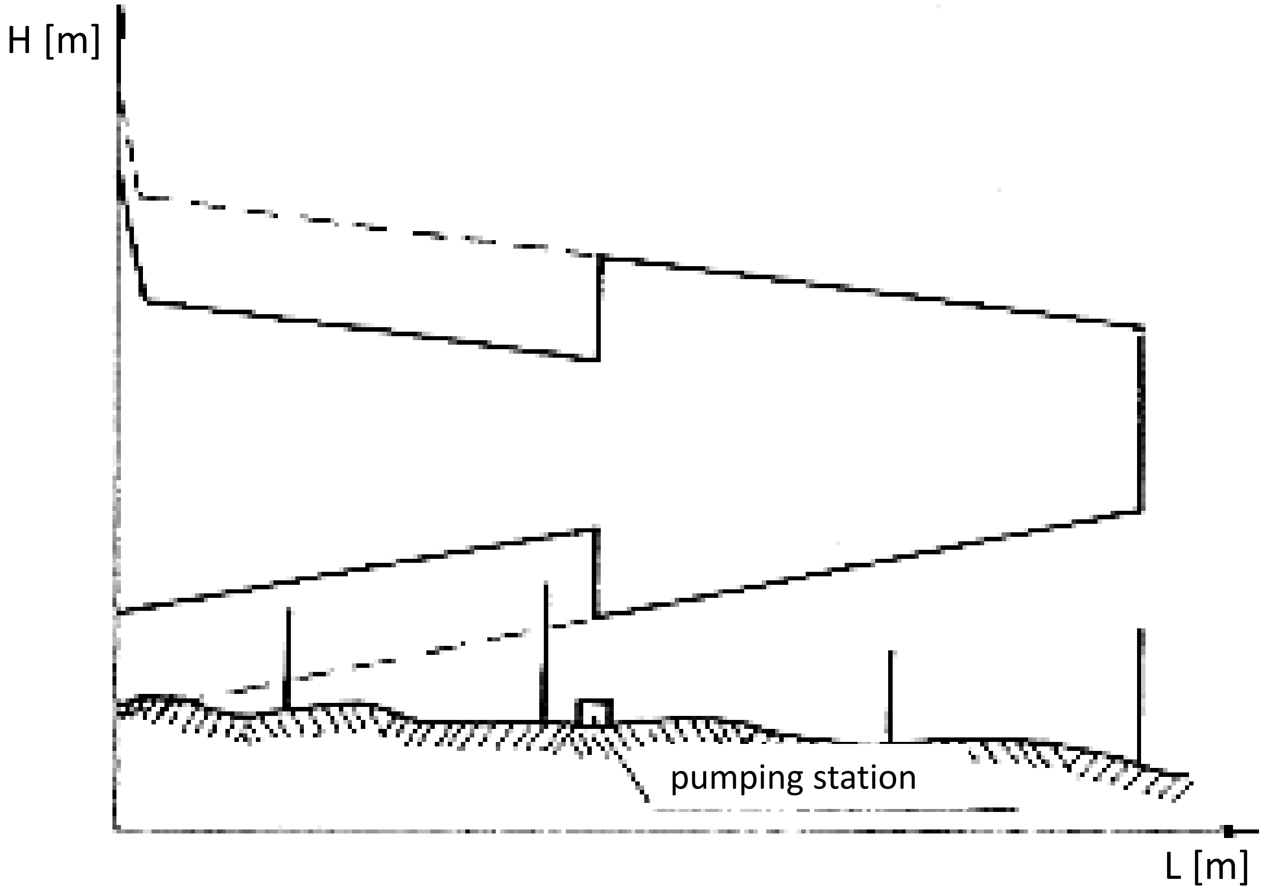


Piezometric graph for a heat network with a pumping station in the supply lines



Piezometric graph for a heat network with a pumping station in the return and supply lines

[PLN/m]



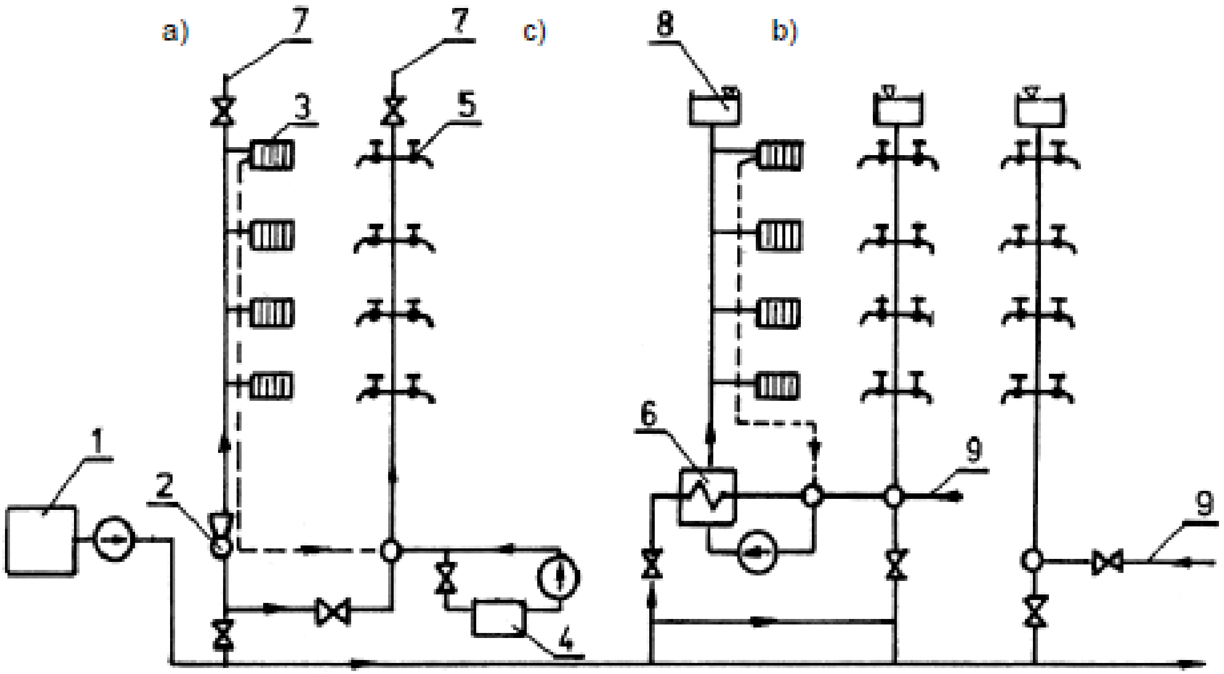
Water networks

Water networks are characterized by the freedom to adapt the slopes to the terrain configuration. The main water pipes are usually laid in shallow, non-steady channels, the direction and size of the slope of the supply and return pipes are the same.

Usually, both wires are laid side by side to facilitate assembly, inspection and maintenance. The minimum dips and bottoms of ducts are about 1.5‰.

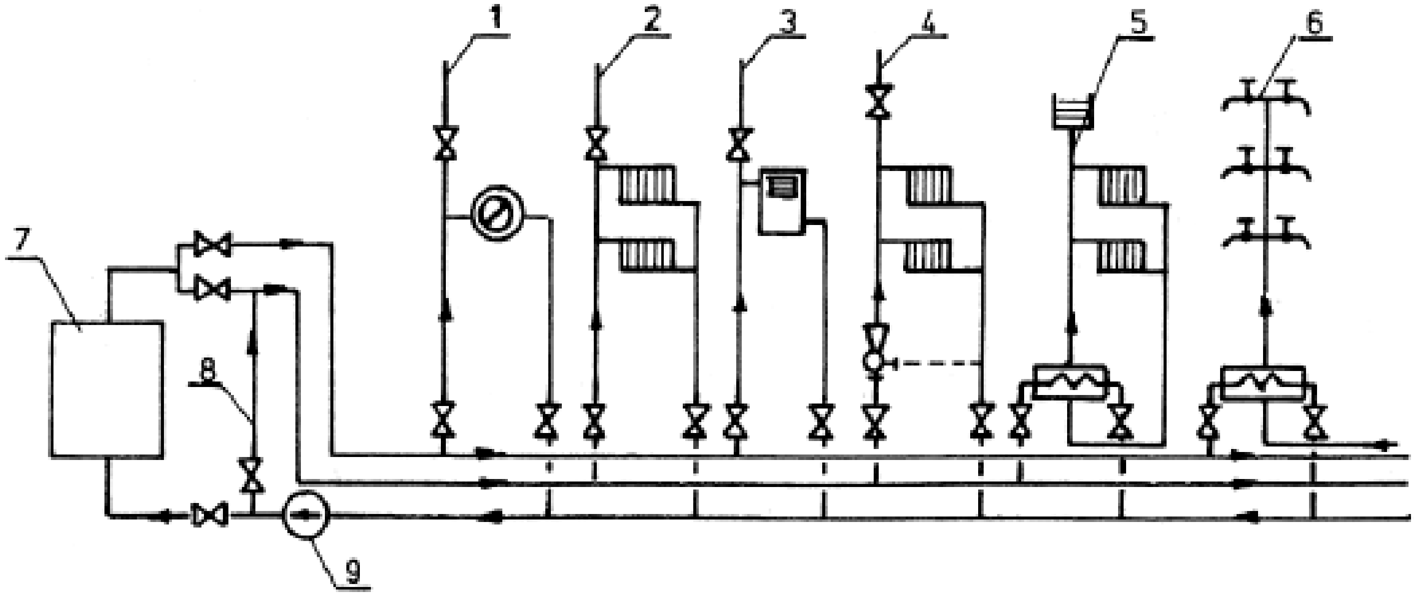
If the heating network is laid in not very long sections, the water heating network pipes can be laid without a slope.

Diagram of a single-pipe water heating network



a) with hydroelevator, b) with heat exchanger, c) direct connection
1 – power station, 2 – hydroelevator, 3 – receivers, 4 – water tank, 5 – domestic hot water, 6 – heat exchanger, 7 – vent, 8 – pressure vessel, 9 – supplementary water

Diagram of a three-pipe water heating network

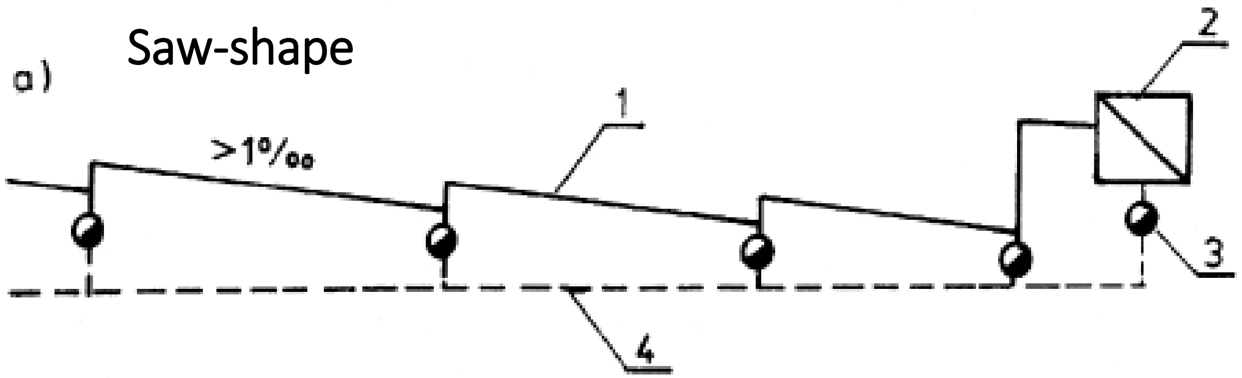


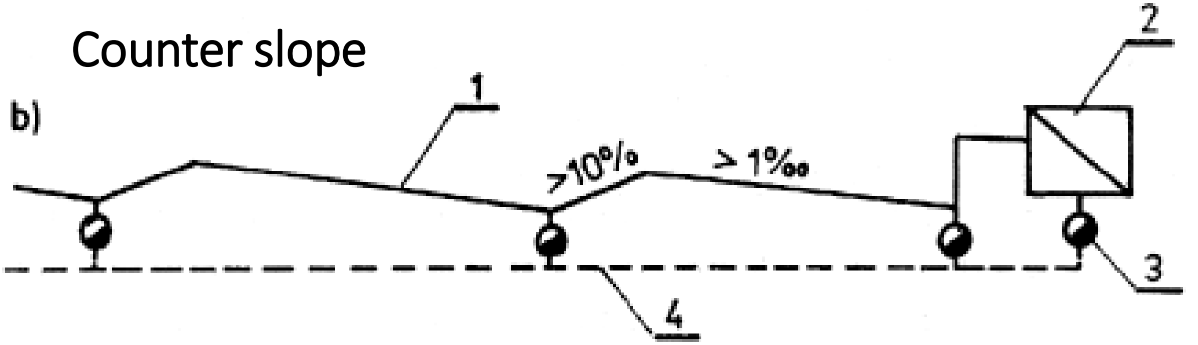
1 – directly connected technology receivers, 2 – directly connected room heating, 3 – directly connected air heaters, 4 – room heating connected via hydroelevator, 5 – room heating connected via heat exchanger, 6 – domestic hot water connected via heat exchanger, 7 – power station, 8 – controll pipe, 9 – network pump

Steam networks

Steam pipes should always be run with a slope to allow condensate to flow to the lowest drainage devices. In case of incompatibility of the steam and condensate flow directions, the steam flow rate should be reduced, and thus the diameter of the pipes should be increased. The condensate network must be constructed in such a way as to ensure a gravitational flow of condensate into the tank as close as possible to the heat source. The minimum line drop for a gravitational condensate drain is 3‰.

Steam networks


Saw-shape


Counter slope

1 – steam, 2 – receiver, 3 – dehydrator, 4 – condensate

Condensate management

- inevitable losses,
- unjustified losses,
- types of drainage devices,
- requirements for steam traps,
- controlling the operation of steam traps.

Condensate management

Losses unavoidable-losses related to the operation of steam devices. During the correct use of these devices, losses can be minimized. The inevitable losses include:

- release of water during desilting or desalination of boilers,
- the use of steam blowers to clean the heating surface of boilers,
- using steam to drive auxiliary equipment in the boiler room,
- that occurring during the boiler start-up, especially if the steam is discharged into the atmosphere (more so if steam superheaters or flow boilers are blown),
- that in pump and turbine seals,
- that in safety valves.

Condensate management

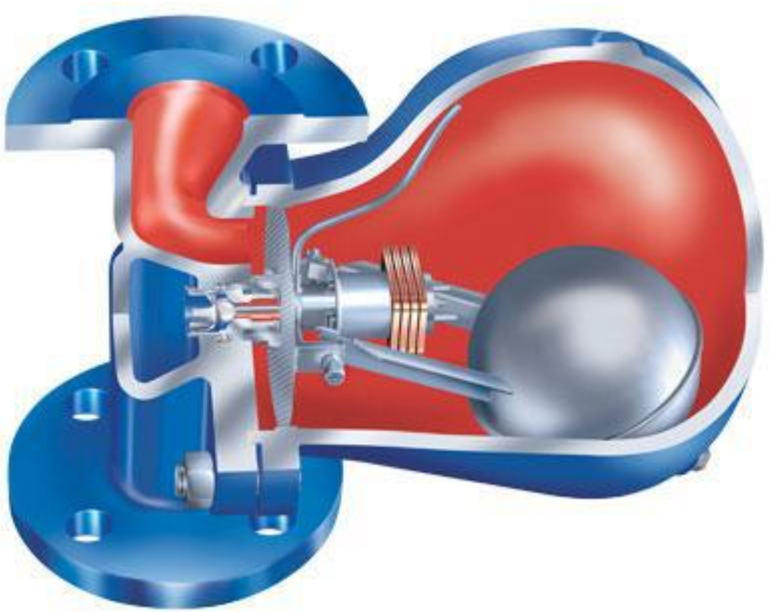
Requirements for the correct construction and operation of steam traps:

- simple construction and use of publicly available materials,
- self-acting,
- small dimensions,
- insensitivity to mechanical and chemical condensate and corrosion,
- the convenience of disassembly, cleaning and replacement of spare parts,
- strength and tightness,
- correct operation within the limits of pressure, temperature and mass fluctuation as much as possible,
- ease of work control.

Condensate management

Types of traps in terms of the principle of operation:

- siphon traps,
- steam traps with closed float,
- dehydrated with an open float,
- throttling separators,
- plate evaporators (thermodynamic).



Part 4

Piping

Pipes of district heating networks

Ways and systems of water circulation in a heating installation:

- pipe types and their implementation,
- standard pipe thickness,
- methods of connecting pipe elements,
- pre-insulated pipes,
- methods of joining pre-insulated pipes,
- additional equipment of heating network pipes,
- methods of laying the heating network wires,
- insulation of pipes.

Pipes of district heating networks

The basic ways of water circulation in a heating installation:

- natural circulation – in natural circulation, automatic water circulation is caused in the water boiler by a difference in water density before and after the boiler (pipe diameter increased).
- forced circulation – circulation pumps are installed in the forced circulation, whose task is to overcome the flow resistance and the difference in the height of the water network. In both circuits, two systems are distinguished:
  - ✓ open (solid fuel),
  - ✓ closed.

Pipes of district heating networks

Types of pipes used in heating systems:

- Steel,
- Copper ores,
- Plastic.

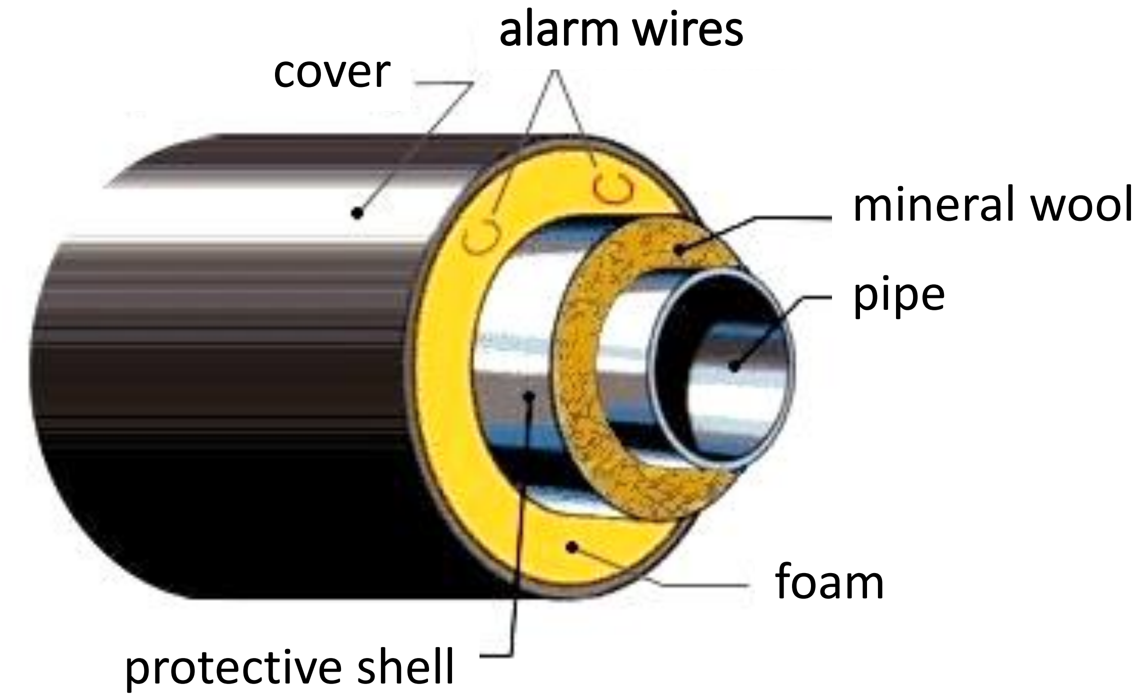
Depending on the method of implementation, we distinguish:

- Welded seams, welded,
- Seamless, rolled or drawn lines.

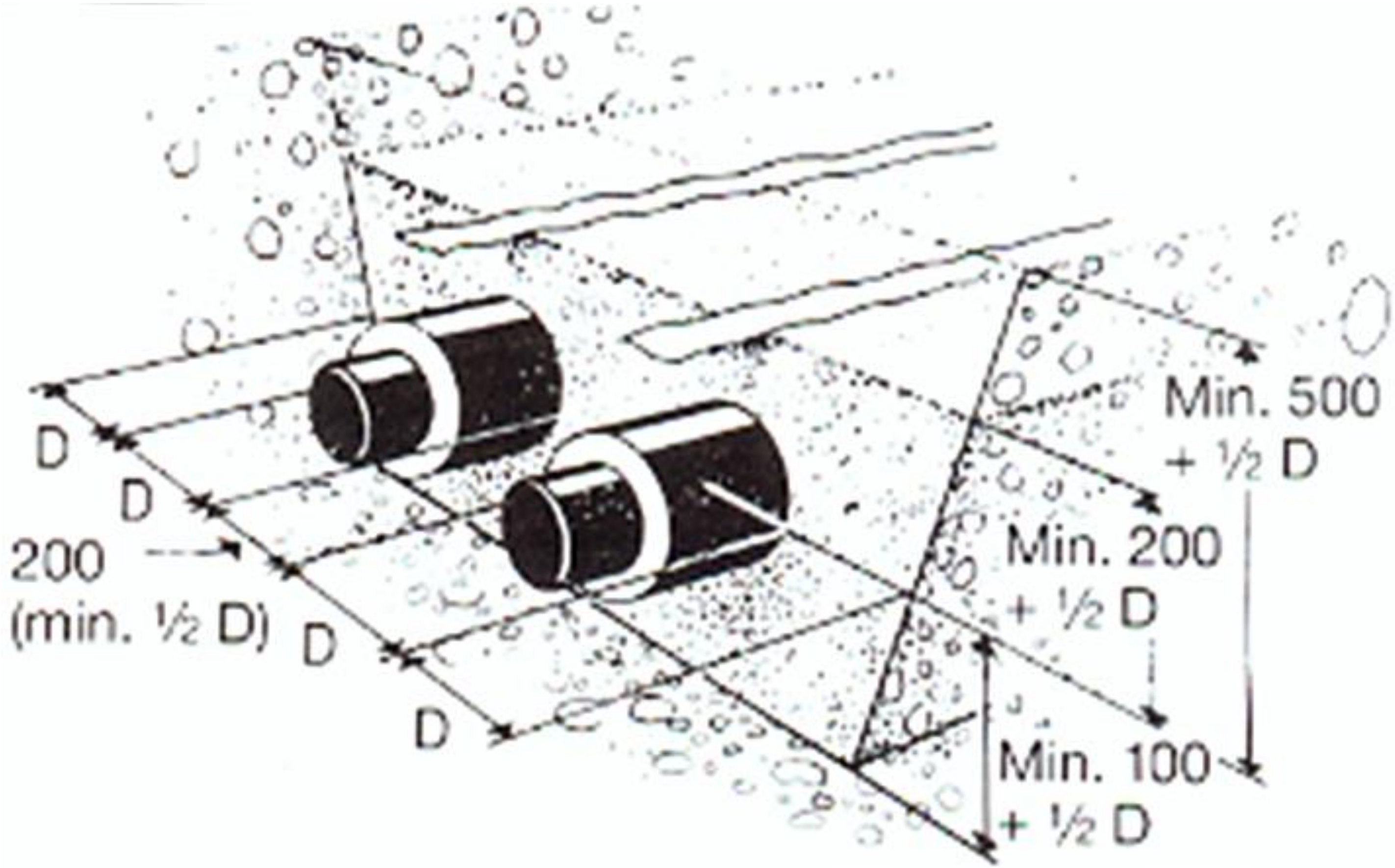
Wall thickness of pipes have three dimensions: for light, medium and heavy pipes. Medium pipes are used in heating. There are two basic ways to connect pipes:

- Inseparable,
- Separable.

Pipes of district heating networks



A typical cross section of the excavation



Pipes of district heating networks

The connection points of the steel line pipes are insulated using special sleeves:

- made of metal, screwed,
- heat shrinkable,
- welded.

Equipping the heating network pipes with fittings is used to direct the movement of the heat carrier. Depending on the tasks fulfilled by the fittings, it can be divided into controlling, protecting and auxiliary.

Pipes of district heating networks

Ways of laying the heating network wires:

- Ground,
- Underground,
- Transitive channels,
- Semi-recessed channels,
- Intransitive channels.

Pipes of district heating networks

Requirements for insulating materials:

- low thermal conduction coefficient,
- high flash point,
- lightness,
- high mechanical strength,
- low water absorption,
- low price of insulating material,
- low cost of execution,
- low cost of maintenance of insulation.

There's no ideal insulation!

Diameters of insulated pipes

Diameters		Water temperatures							
d_{nom}	d_{out}	90–95/70^{o}C				150/70^{o}C			
		Insulation thickness		Outside diameter		Insulation thickness		Outside diameter	
		supply	return	$D_{out\_ supply}$	$D_{out\_ return}$	supply	return	$D_{out\_ supply}$	$D_{out\_ return}$
15	22	40	30	120	100	50	30	140	100
20	27	40	30	130	110	50	30	150	110
25	34	40	30	135	115	50	30	155	115
32	42	40	30	140	120	60	30	180	120
40	48	40	30	150	130	60	30	190	130
50	60	40	30	160	140	70	30	220	140
65	76	50	40	200	180	80	40	240	180
80	89	50	40	210	190	80	40	270	190
100	115	50	40	235	215	80	40	295	215
125	140	60	50	280	260	100	50	360	260
150	170	60	50	310	290	100	50	390	290
200	220	70	60	380	360	110	60	460	360

Pipes of district heating networks

1 – low temperature pipeline

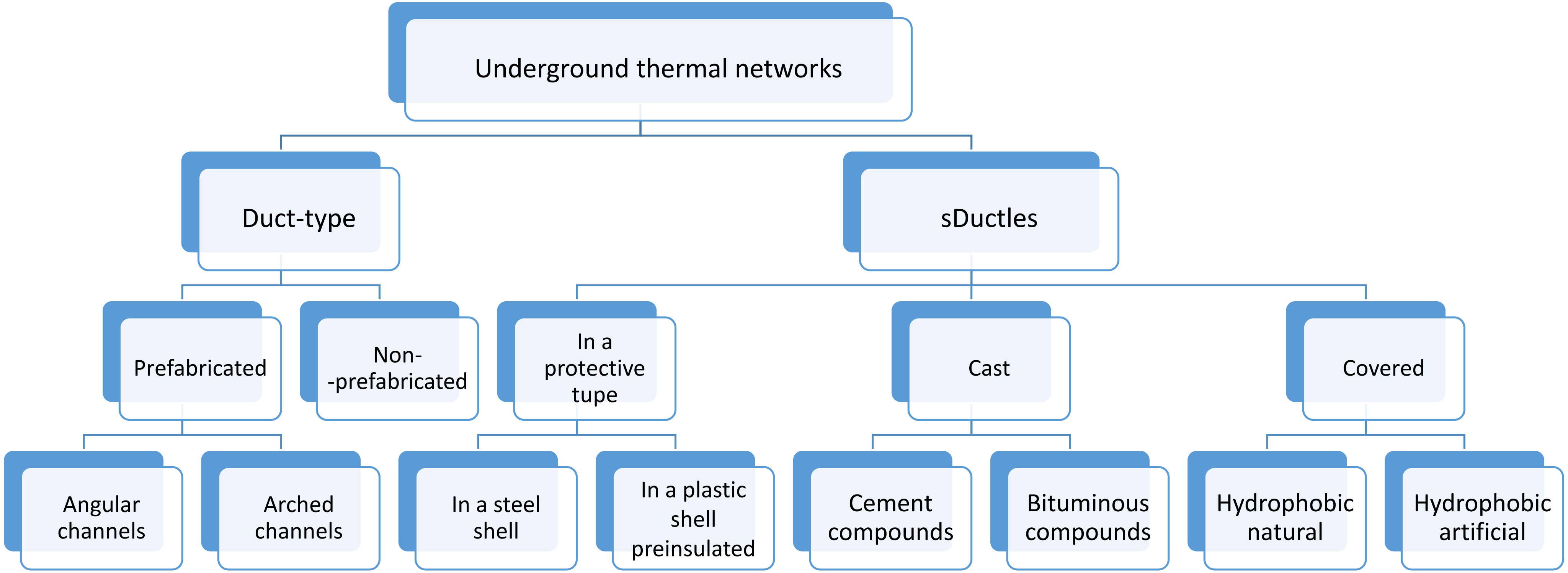
2 – ROCKMATA

3 – protective shell made of sheet metal

An example of the application of thermal insulation on a heating pipe.

Source: LOGSTOR

Ways of laying thermal networks



Underground thermal networks

Duct-type

sDuctles

Prefabricated

Non-
-prefabricated

In a
protective
tupe

Cast

Covered

Angular
channels

Arched
channels

In a steel
shell

In a plastic
shell
preinsulated

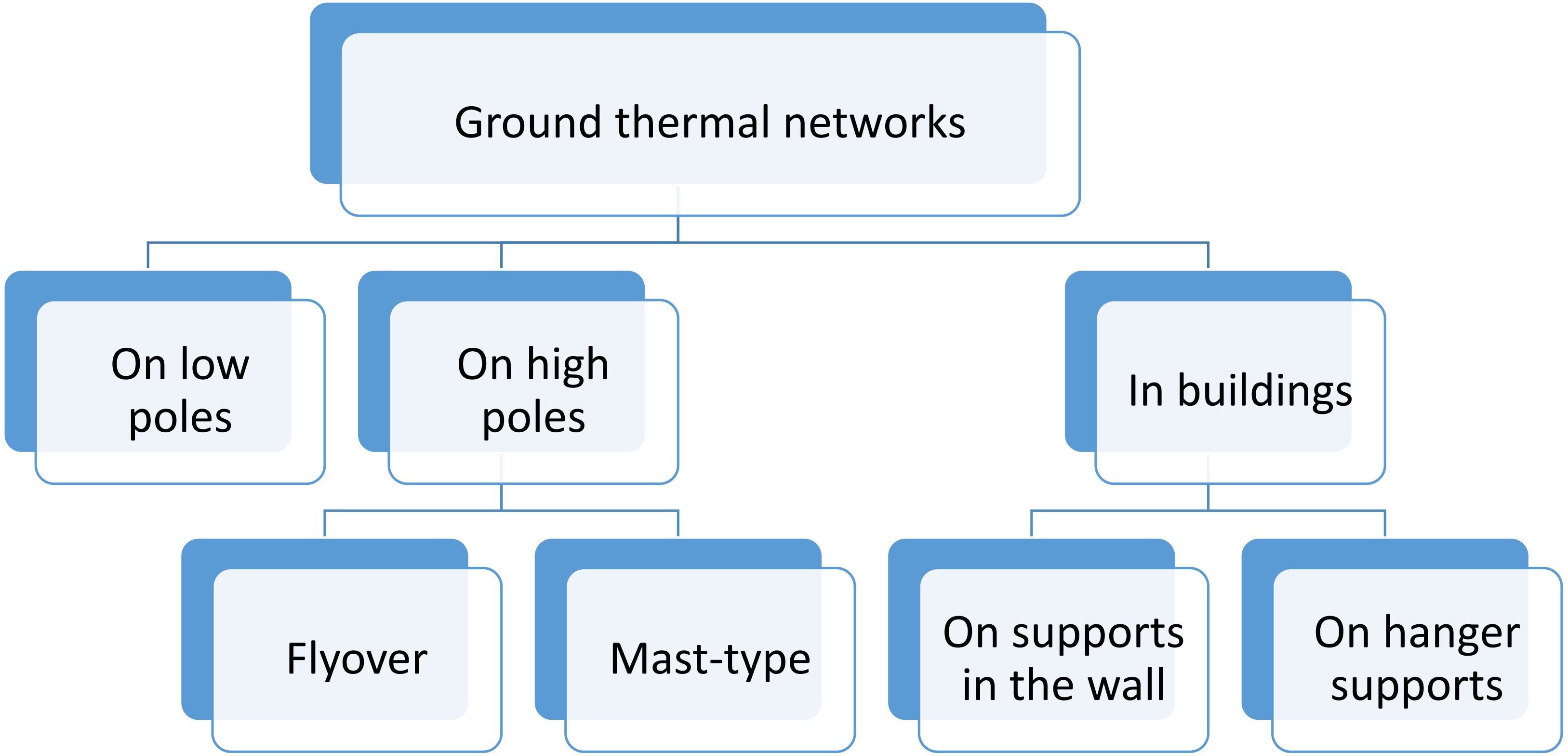
Cement
compounds

Bituminous
compounds

Hydrophobic
natural

Hydrophobic
artificial

Ways of laying thermal networks



Ground thermal networks

On low poles

On high poles

Flyover

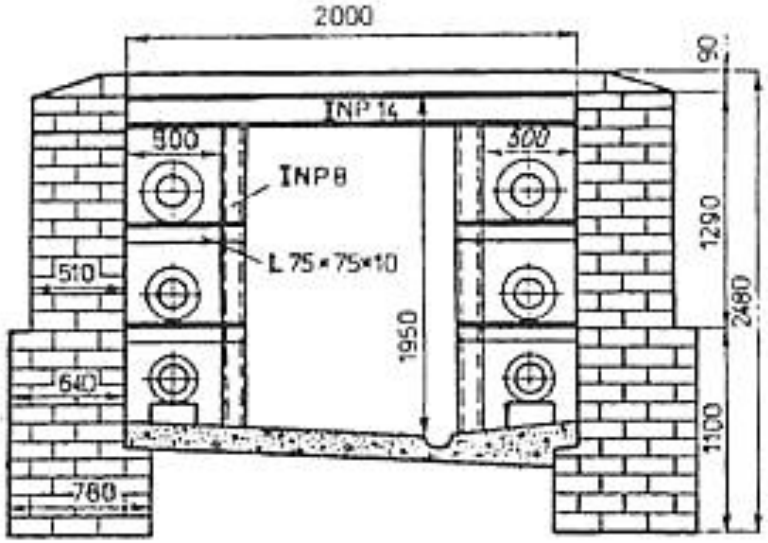
Mast-type

In buildings

On supports in the wall

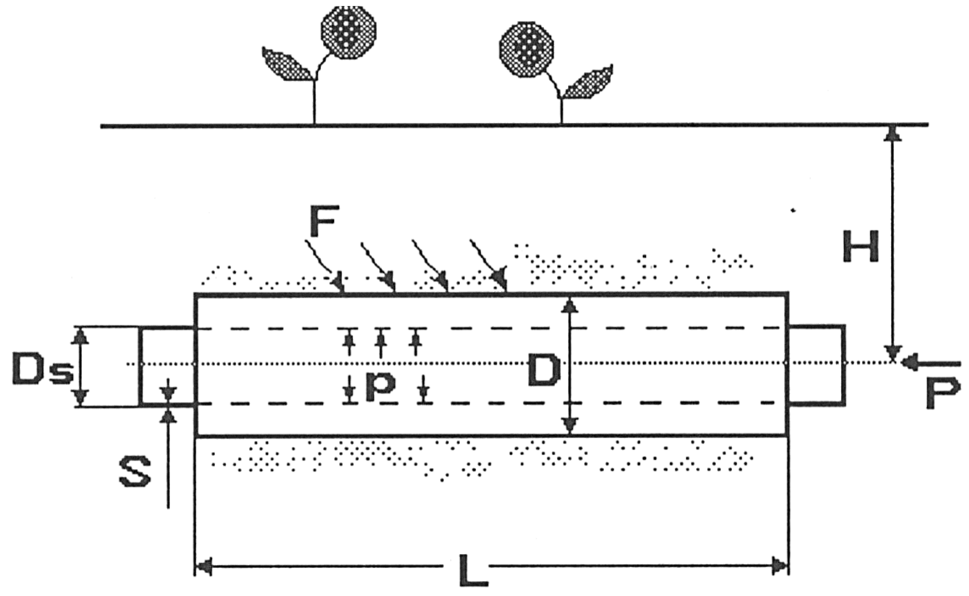
On hanger supports

Ways of laying thermal networks



Thermal network carried out
in the transitive channel

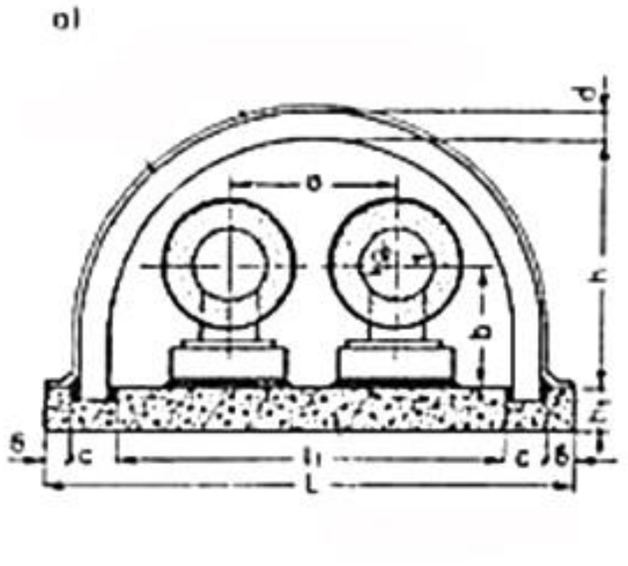
Ways of laying thermal networks

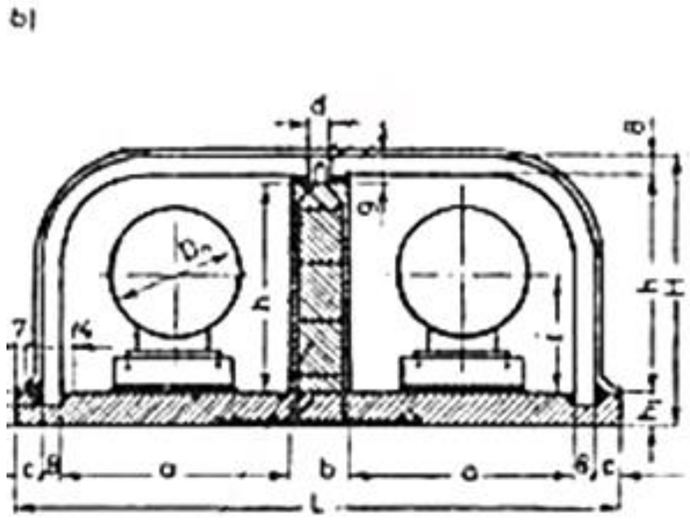


Heating network without channel, laid directly in the ground

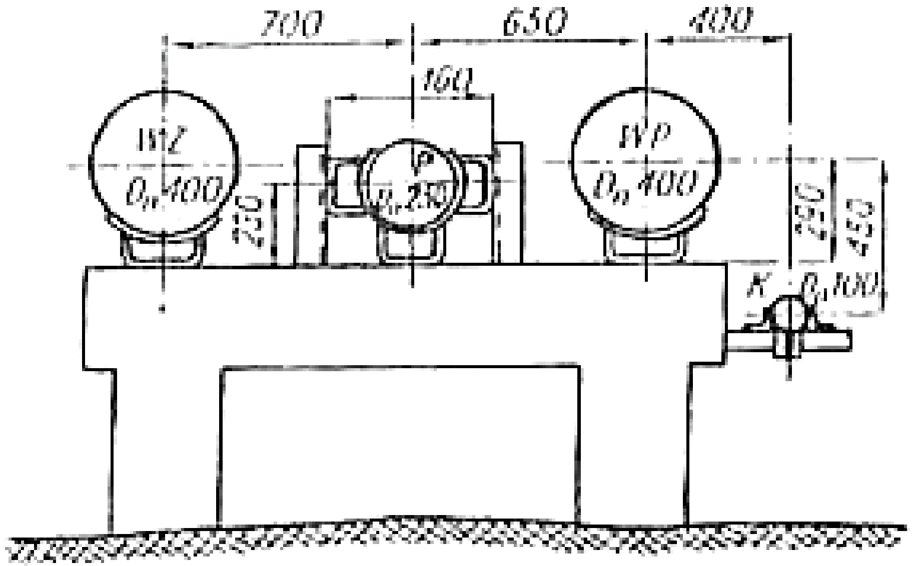
Ways of laying thermal networks

Underground canal networks run in the intransitive channel





Ways of laying thermal networks



Pre-insulated network and overhead network on low supports

Ways of laying thermal networks

Pre-insulated network

Ways of laying thermal networks

Pre-insulated network

Part 5

Calculations, compensation

Hydraulic calculations

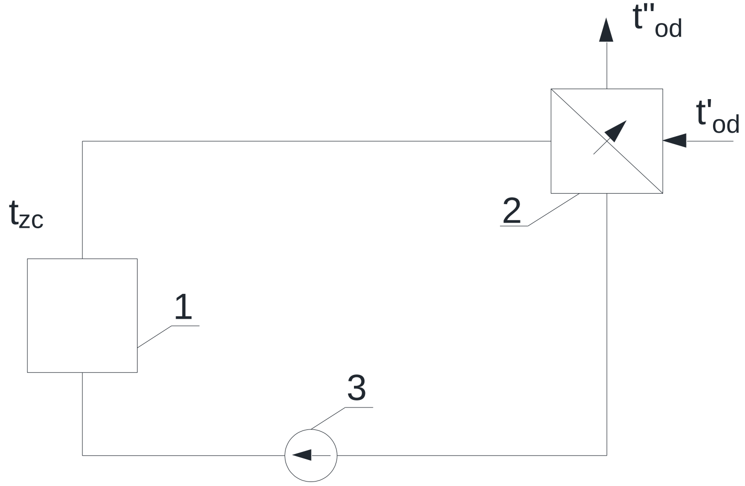
Hydraulic calculations of thermal networks

- Determination of the parameters of the heat carrier depending on its intended use,
- Piezometric graph,
- The volume flow of the heat carrier,
- Diameter of the heating network pipeline,
- The actual velocity of the heat carrier in the district heating network.

Hydraulic calculations – temperature of the source

$$t_{zc} = t''_{od} + \Delta t + \Delta t_s$$

t''_{od} – required temperature in heat receiver
Δt – temperature difference in receiver
Δt_s – temperature drop in the heat network between the heat source and the receiver



Simplified diagram of thermal network. 1 – heat source, 2 – receiver, 3 – pump

Selection of the diameter of the district heating pipeline
Method 1 (constant pressure drop)

$$R_{śr} = \frac{\Delta p_{dysp} - \Delta p_{węęz}}{l + l_z}$$

Δp_{dysp} The available pressure at the beginning of the network (180 kPa)

$\Delta p_{węęz}$ – required available pressure for the most distant node (about 60 kPa)

l – length of the network pipeline (supply + return) (2 x 300 m)

l_z – substitute length for local resistances (according to the resistance balance) approx. = 20%

$$R_{śr} = \frac{1800\,000\,\mathrm{Pa} - 60\,000\,\mathrm{Pa}}{2 * 300\,\mathrm{m} + 120\,\mathrm{m}} = 167\,\mathrm{Pa/m}$$

Selection of the diameter of the district heating pipeline Method 2 (speed criterion – adjusting the available pressure in the source to the designed network)

Velocity recommended:

- Main networks 2÷3 m/s
- Local networks and bus branches 1.0÷2.0 m/s
- Connections to buildings < 1.0 m/s

Hydraulic calculations

Unit pressure drop in the network

$$R = 0.81 * \lambda * \frac{\dot{G}^2}{\rho * d_w^5} \rightarrow [\mathrm{Pa/m}]$$

$\dot{G}$ – liquid flow [kg/s]

ρ – density of liquid [kg/m^3]

d_w – inside diameter of the pipe [m]

λ – coefficient of friction in the pipe (from the Walden or Colebrook-White formula) Walden's formula:

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{6.1}{\mathrm{Re}^{0.915}} + 0.268 * \varepsilon\right)$$

Evample calculations

Flow G = 10 kg/s

Pipeline $d_z * s$ = 133 x 4 mm; velocity w = 0,9 m/s

Water kinematic viscosity $v = 3.26\text{ e}10^{-7}\ \mathrm{m}^2/\mathrm{s}$

$$\mathrm{Re} = \frac{w \cdot d}{v}$$

$$Re = \frac{0.9\ \mathrm{m/s} * (0.133\ \mathrm{m} - 2 * 0.004\ \mathrm{m})}{3.26 * 10^{-7}\ \mathrm{m}^2/\mathrm{s}} = 345\,000$$

$$\varepsilon = \frac{k}{d_{w,s}} = \frac{0.001\,\mathrm{m}}{(0.133 - 2 \cdot 0.004\ \mathrm{m}} = 0.008$$

Evample calculations

flow G = 10 kg/s
pipeline $d_z * s$ = 133 x 4 mm w = 0.9 m/s
water temperature 90°C; density = 965 kg/m^3

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{6.1}{\mathrm{Re}^{0.915}} + 0.268 * \varepsilon\right) \qquad R = 0.81 * \lambda * \frac{\dot{G}^2}{\rho * d_w^5} \rightarrow [\mathrm{Pa/m}]$$

$$\lambda = \left[-2\log\left(\frac{6.1}{345\,000^{0.915}} + 0.268 * 0{,}008\right)\right]^{-2} = 0.035$$

$$R = 0.81 * 0.035 * \frac{(10\ \mathrm{kg/s})^2}{965\ \mathrm{kg/m^3} * (0{,}125\ \mathrm{m})^5} = 96.3\ \mathrm{Pa/m}$$

Heat losses of the network: Ductless networks (run without a channel)

Nomenclature:

t – temperature of the medium in the pipe

t_{gr} – line ground temperature

R_g – thermal resistance of the ground

R_{iz} – thermal insulation resistance

Λ_{gr} – soil thermal conductivity

Λ_{iz} – thermal conductivity of insulation

d – diameter of steel pipe

D – pipe insulation diameter

h – depth of pipe (to the axis)

a – additional loss on fittings (5%)

Unit thermal loss of the network

$$q_{str} = \frac{t - t_{gr}}{R_g + R_{iz}} \rightarrow [\mathrm{W/m}]$$

Heat losses of the network: Ductless networks (run without a channel)

- Total network heat loss (transfer loss)

$$\dot{Q}_{str} = \dot{Q}^{zas}_{str} + \dot{Q}^{powr}_{str} = \left(q^{z}_{str} + q^{p}_{str}\right) * l * (1+a) \rightarrow [W]$$

- Temperature drop in the most distant receiver

$$\Delta t_z = \frac{q^{zas}_{str} * l * (1+a)}{\dot{G} * c_p}$$

- Pipes laid deep **h/D > 2.5**
- Resistance of the ground

$$R_g = \frac{1}{2 * \pi * \lambda_g} * \ln \frac{4 * h}{D}$$

$$\lambda_g = 0.29 + 2.79 * (0.97)^{t_g}$$ (Petri equasion)

- Resistance of the insulation

$$R_{iz} = \frac{1}{2 * \pi * \lambda_{iz}} * \ln \frac{D}{d}$$

Example

Balance the thermal network transmission losses for data:
h = 1.2 m; D = 208 mm; d = 108 mm (108 x 4)
λ_{iz} = 0.035 W/mK; t_g = +8°C; network 130/70°C
G = 5.17 kg/s

$$R_{iz} = \frac{1}{2 * \pi * \lambda_{iz}} * \ln \frac{D}{d}$$

$$\lambda_g = 0.29 + 2.79 * (0.97)^{t_g}$$

$$R_g = \frac{1}{2 * \pi * \lambda_g} * \ln \frac{4 * h}{D}$$

$$q_{str} = \frac{t - t_{gr}}{R_g + R_{iz}} \rightarrow [\mathrm{W/m}]$$

$$R_{iz} = \frac{1}{2 * \pi * 0.035\ \mathrm{W/mK}} * \ln \frac{0.208\ \mathrm{m}}{0.108\ \mathrm{m}} = 2.98 \frac{\mathrm{mK}}{\mathrm{W}}$$

$$\lambda_g = 0.29 + 2.79 * (0.97)^8 = 2{,}47\ \mathrm{W/mK}$$

$$R_g = \frac{1}{2 * \pi * 2.47\ \mathrm{W/mK}} * \ln \frac{4 * 1.2\ \mathrm{m}}{0.208\ \mathrm{m}} = 0.2 \frac{\mathrm{mK}}{\mathrm{W}}$$

$$q_{str}^{z} = \frac{130°C - 8°C}{0.2\ \mathrm{mK/W} + 2.98\ \mathrm{mK/W}} = 38.4\ \mathrm{W/m}$$

$$q_{str}^{p} = \frac{70°C - 8°C}{0.2\ \mathrm{mK/W} + 2.98\ \mathrm{mK/W}} = 19.5\ \mathrm{W/m}$$

$$\dot{Q}_{str} = \dot{Q}^{zas}_{str} + \dot{Q}^{powr}_{str} = \left(q^{z}_{str} + q^{p}_{str}\right) * l * (1 + a) \rightarrow [\mathrm{W}]$$

$$\dot{Q}_{str} = \left(38.4\,\mathrm{W/m} + 19.5\,\mathrm{W/m}\right) * 300\ \mathrm{m} * (1 + 0.05) = 18\,240\,\mathrm{W}$$

$$\dot{Q} = \dot{G} * c_p * \left(t_z - t_p\right) = 5.17\,\mathrm{kg/s} * 4190\ \mathrm{J/kgK} * (130 - 70) = 1300\ \mathrm{kW}$$

Transmission efficiency:

$$\eta = \left(1 - \frac{\dot{Q}_{str}}{\dot{Q}}\right) * 100\% = \left(1 - \frac{18.24\,\mathrm{kW}}{1300\,\mathrm{kW}}\right) * 100\% = 98.6\%$$

The supply temperature of the distant heating substation:

$$\Delta t_z = \frac{q_{str}^{zas} * l * (1+a)}{\dot{G} * c_p}$$

$$\Delta t_z = \frac{38.4\,\mathrm{W/m} * 300 * (1+05)}{5.17\,\mathrm{kg/s} * 4190\,\mathrm{J/kgK}} = 0.53\,\mathrm{K} \rightarrow t_z^w = 130°C - 0.53\,\mathrm{K} = 129.47°C$$

$$\Delta t_p = \frac{19.5\,\mathrm{W/m} * 300 * (1+05)}{5.17\,\mathrm{kg/s} * 4190\,\mathrm{J/kgK}} = 0.28\,\mathrm{K}$$

Design exercise

Pipeline design (connection to the building):

1. Routing
2. Profile
3. Diameter calculations/selection

Example data:

Q_A = 200 kW

Q_B = 270 kW

ts/t_r = 140/70^{o}C

ρ = 954.7 kg/m^3

Network depth = 0.7 m

Minimum ground cover h_{min} = 0.6 m

Design exercise

Example data:
Q_A = 200 kW
Q_B = 270 kW
ts/t_r = 140/70°C
ρ = 954.7 kg/m^3
Network depth = 0.7 m
Minimum ground cover h_{min} = 0.6 m

Design exercise

Equations:

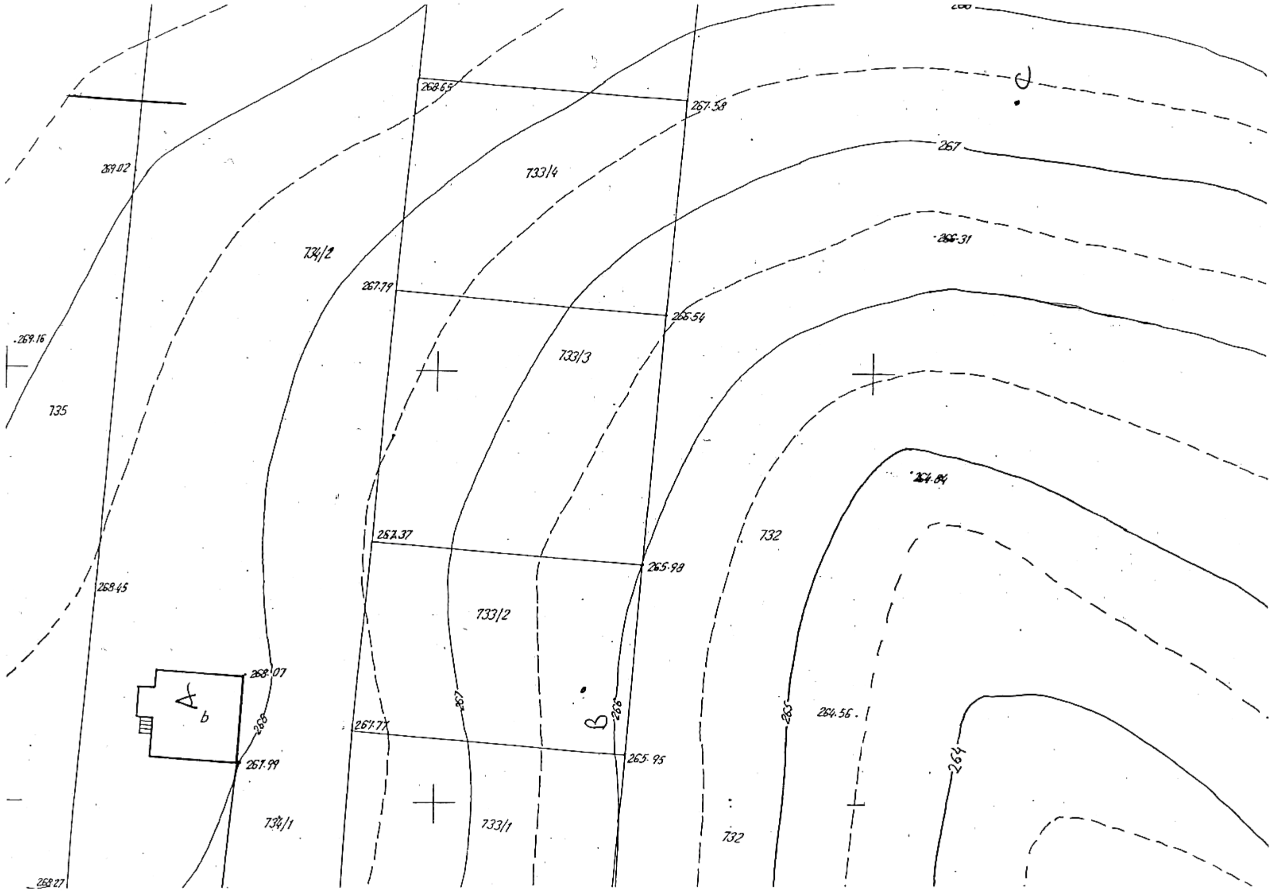
$$\dot{m} = \frac{\dot{Q}}{c_w \cdot (t_s - t_r)} \left[\frac{\mathrm{kg}}{\mathrm{s}}\right] \qquad \dot{V} = \frac{\dot{m}}{\rho} \left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$$

$$\dot{V} = F \cdot w = \frac{\pi \cdot d^2}{4} \cdot w \left[\frac{\mathrm{m}^3}{\mathrm{s}}\right] \qquad d = \sqrt{\frac{4 \cdot \dot{V}}{\pi \cdot w}}$$

$$h = \frac{1}{2}\left(D_1 + D_2\right) + 50\,\mathrm{mm}$$

The map

Design exercise



Compensation of heating network elongation

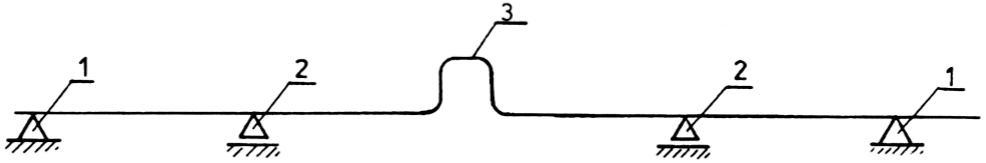
Thermal elongation compensation:

- types of compensators,
- methods of compensation of thermal elongations of thermal networks,
- advantages and disadvantages of exemplary compensators.

Compensation of heating network elongation

Compensation methods for thermal elongations:

- natural,
- installing supports,
- using compensators.



The principle of installing supports
1 – fixed, 2 – movable, 3 – compensators

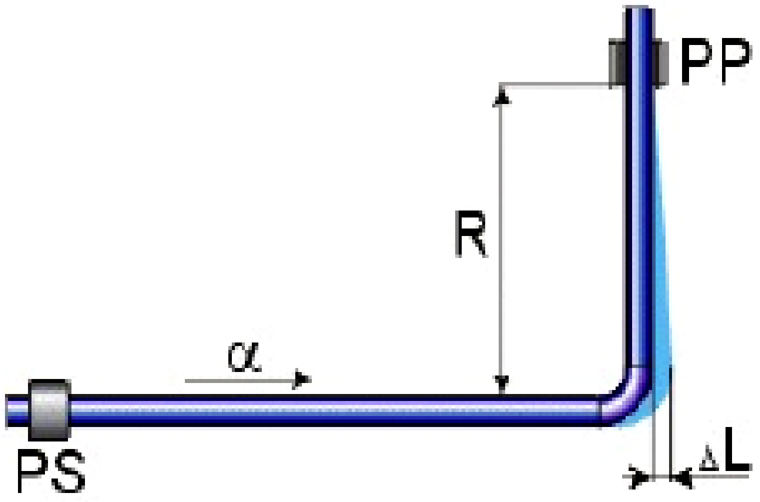
Compensation of heating network elongation natural

$$R = K\sqrt{d\Delta L}$$

ΔL – pipe elongation

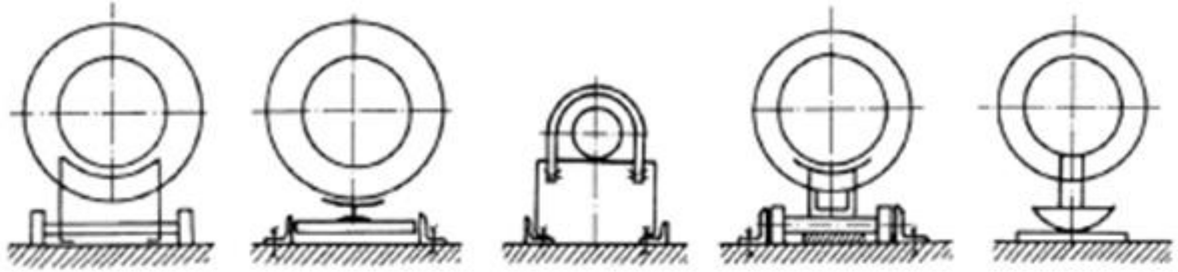
d – internal diameter

K – material factor

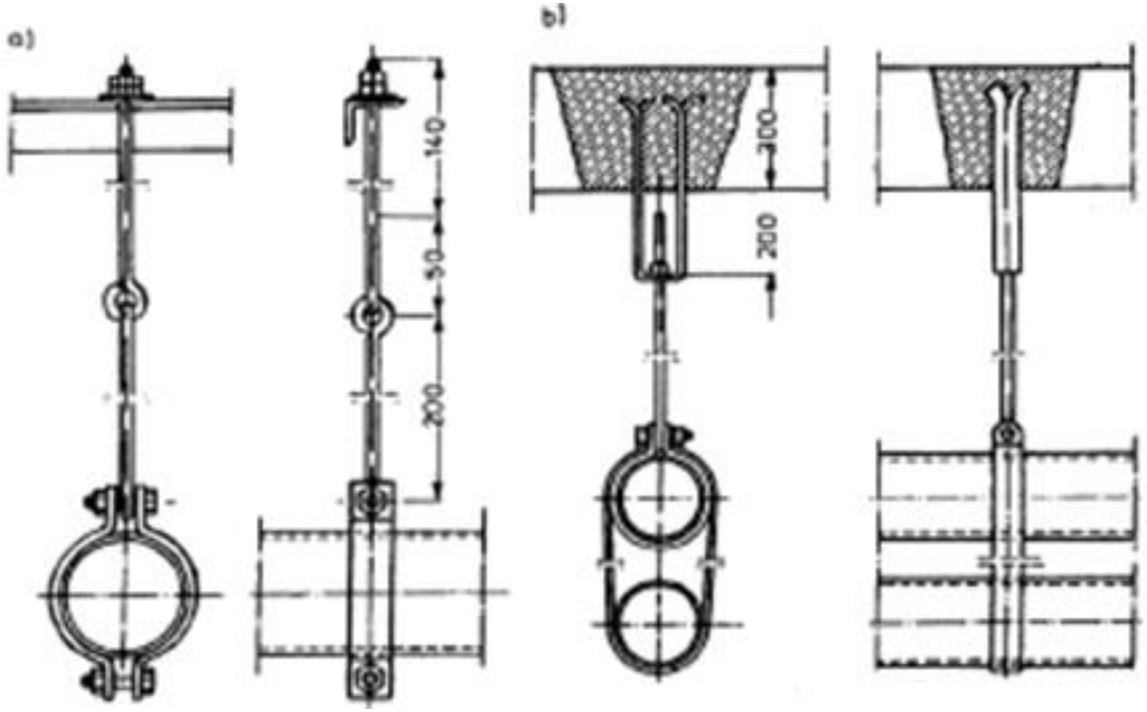


Source: J. Górecki, 1997

Compensation of heating network elongation



movable supports



suspension supports

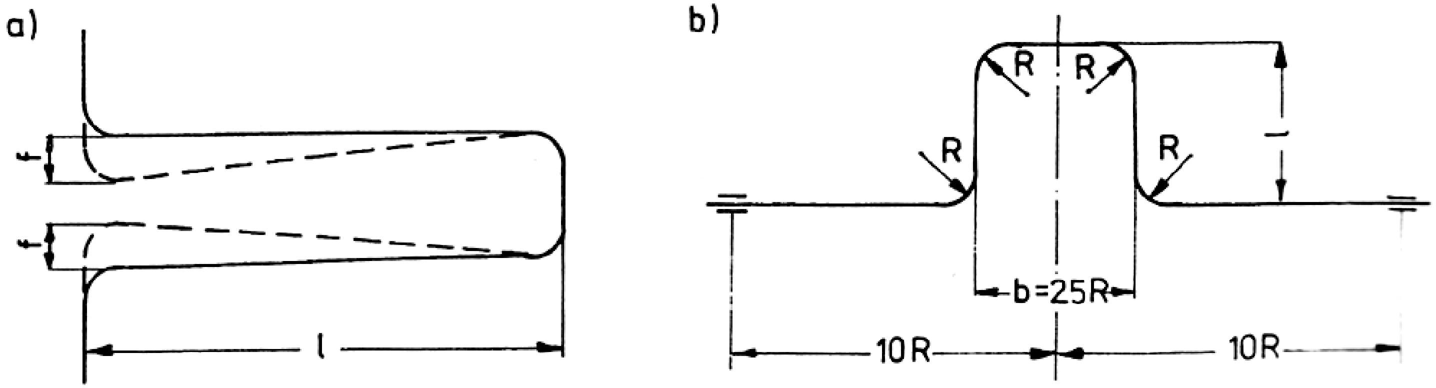
Source: J. Górecki, 1997

Compensation of heating network elongation

Division of compensators due to the construction and the principle of operation:

- u-shaped,
- lyre from smooth pipes,
- lyre from corrugated pipes,
- lyre from corrugated tubes,
- lenticular,
- with elastic tubes and guides,
- with elastic tubes and strengthening rings (so-called yoke compensators),
- anginal,
- articulated,
- wavy multi-layer.

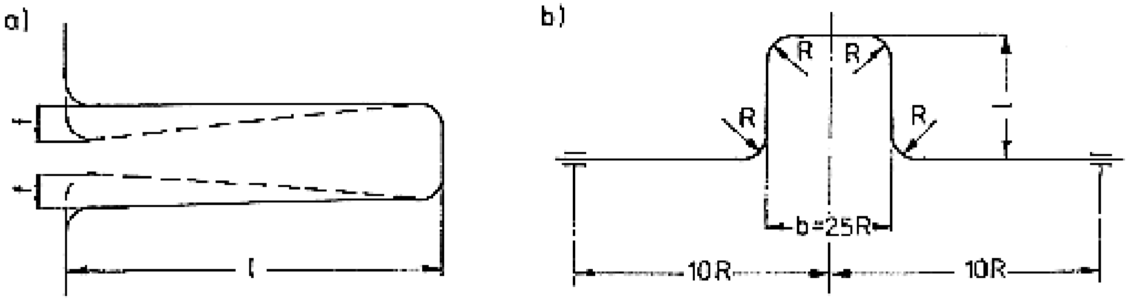
Compensation of heating network elongation



U-shaped compensator: a) deflection of the compensator, b) basic dimensions of the compensator, R – compensation arc of the compensator, l – arc height, b-width, 10R – distance from the compensator axis to the nearest movable support

U-shaped compensator – during pre-assembly work, the pipe is pre-stretched. Mostly used in pipes with a heating medium of high temperature and high pressure. These are the basic compensators commonly used in distribution heat networks.

Compensation of heating network elongation

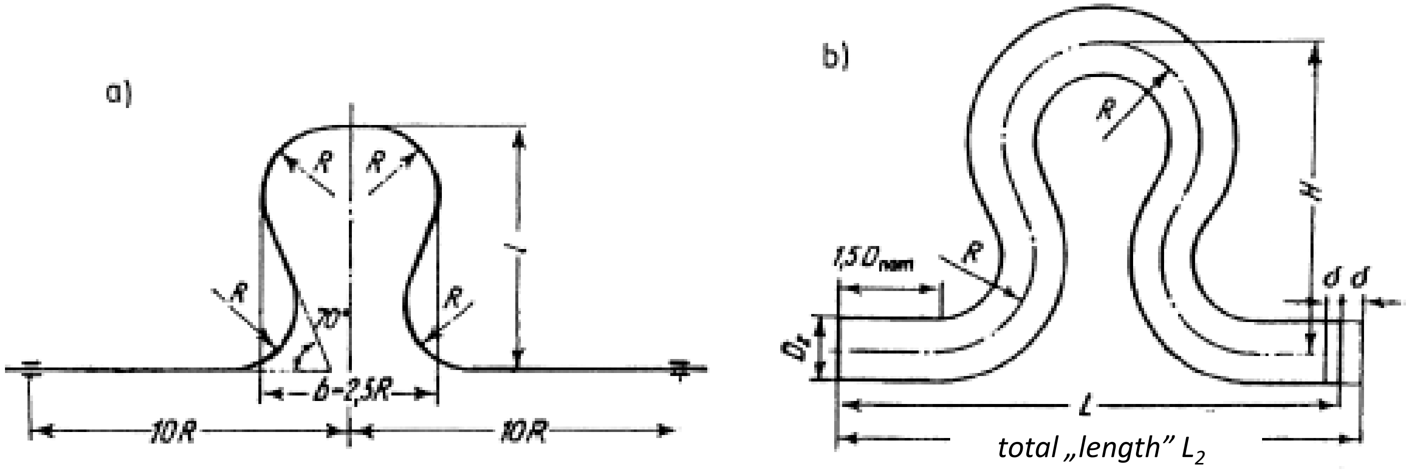


U-shaped compensator

$$\frac{l}{R}=4 \qquad \frac{R}{D}=5$$

$$l=0.205\sqrt{Df}\ [\mathrm{m}]$$

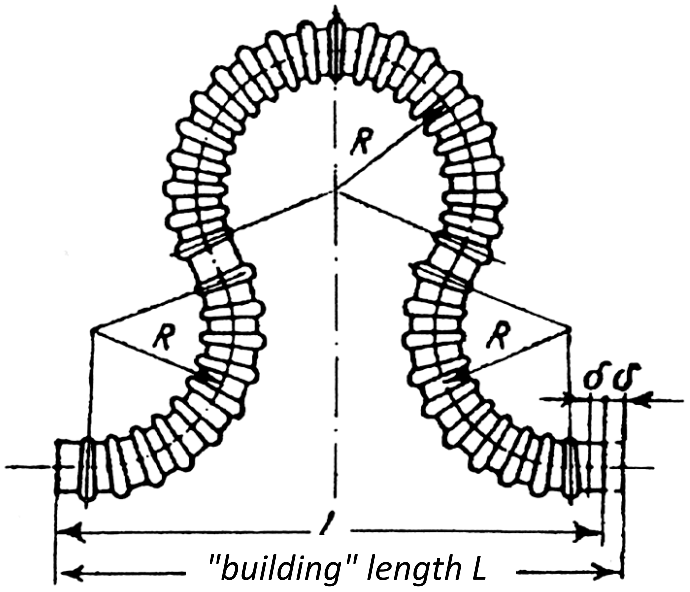
Compensation of heating network elongation



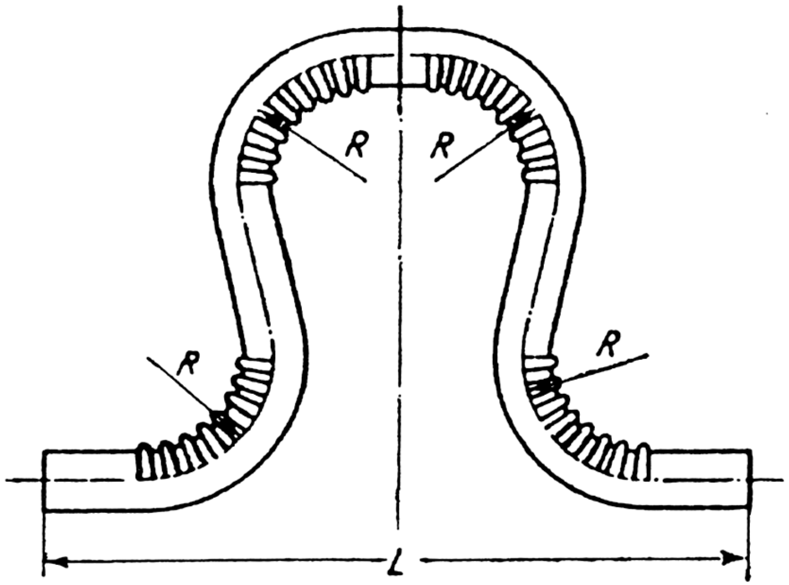
Compensator lire made of smooth pipes – this has more elasticity than the U-shaped compensator. The disadvantage is the occurrence of relatively high stresses in the places of their bending

Source: J. Górecki, 1997

Compensation of heating network elongation



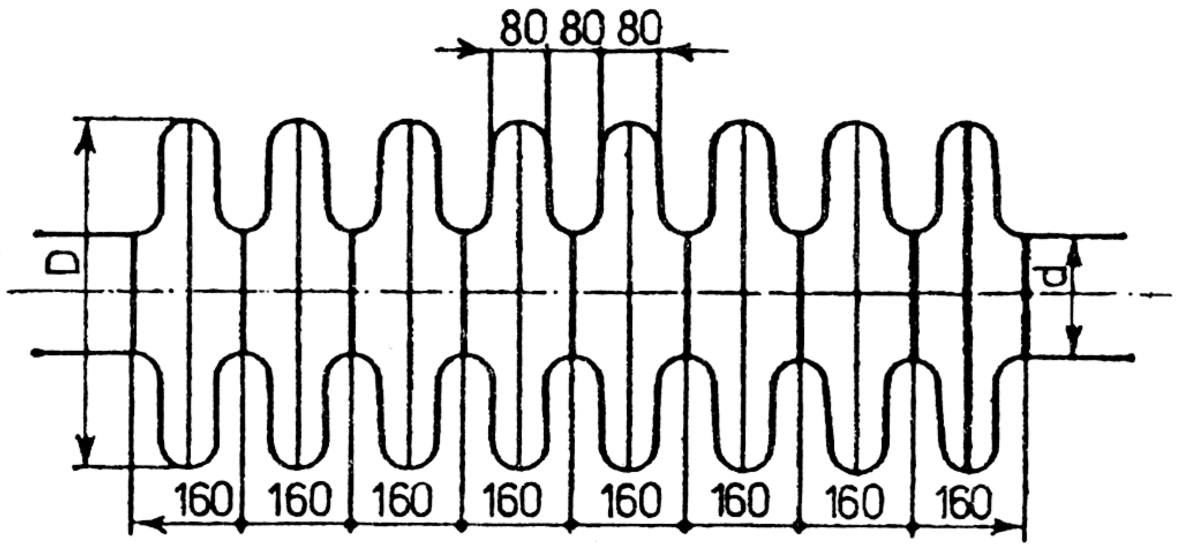
A pipe compensator made of folded pipes



A pipe compensator made of corrugated pipes

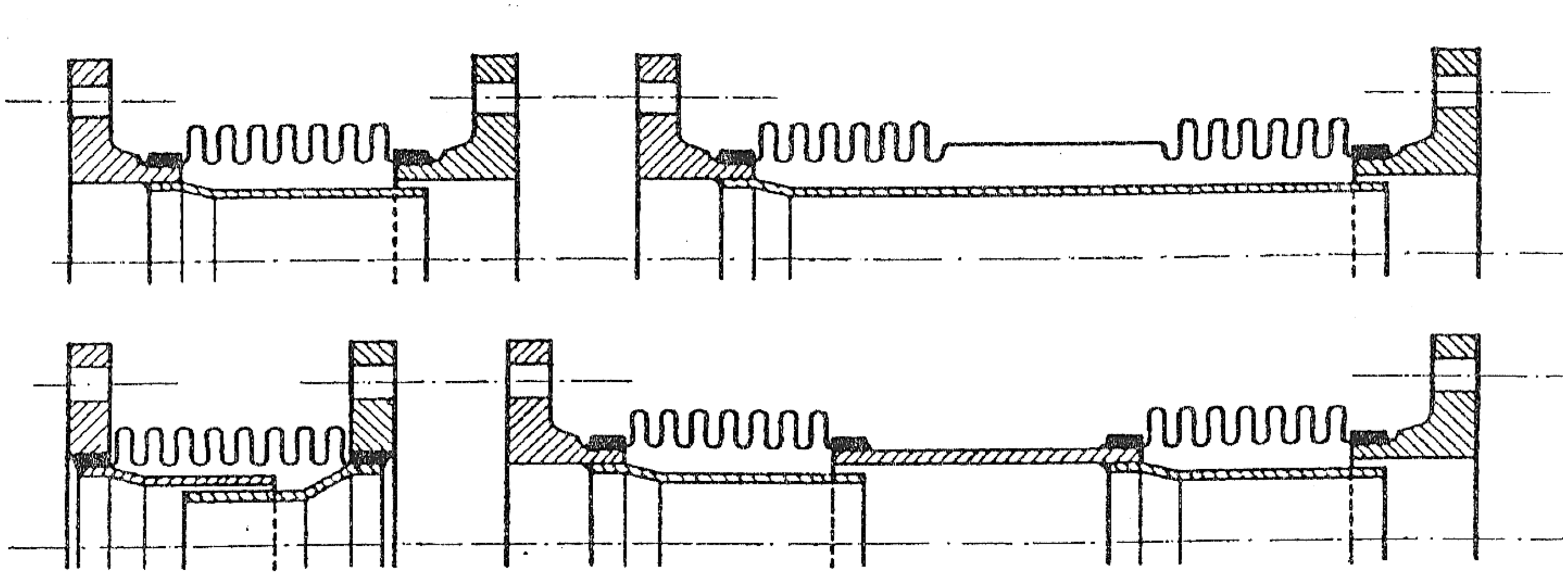
Compensators from folded pipes and corrugated pipes cause a much greater flow resistance than smooth pipe expansion joints, they have a low mechanical strength. They are used in transporting networks with low pressure, low temperature and usually small diameters.

Lenticular compensator

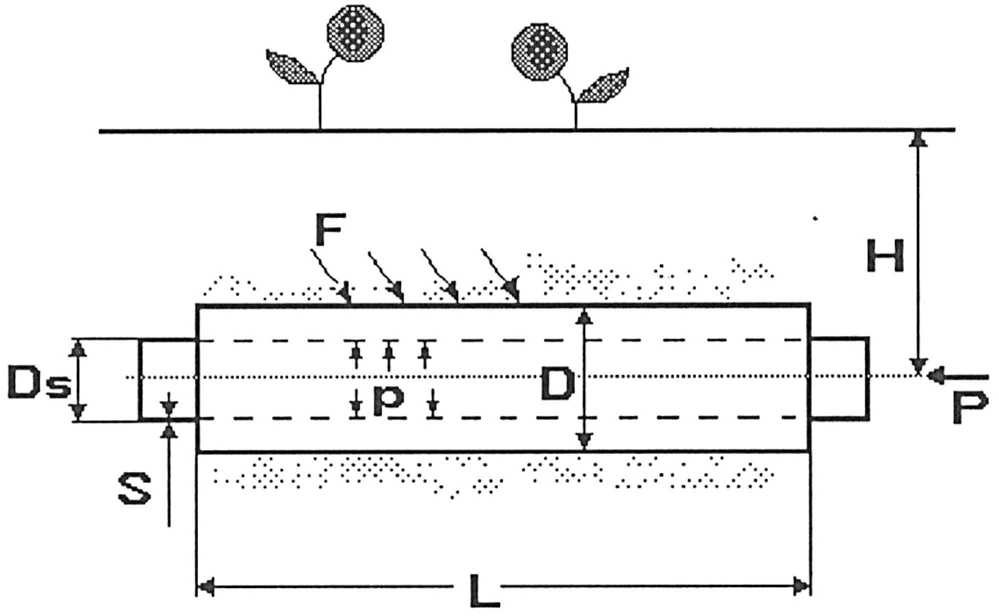


Lenticular compensators – made as straight sections constructed from sheet metal bent in a wave shape. They have low mechanical strength and cause high resistance to flow.

Expansion joints with spring tubes and guides



Elongation compensation of pre-insulated pipes



The pre-insulated pipeline located underground at depth H, is subject to pressure from soil pressure, depending on its density:

$$p = \rho \cdot g \cdot H$$

Elongation compensation of pre-insulated pipes

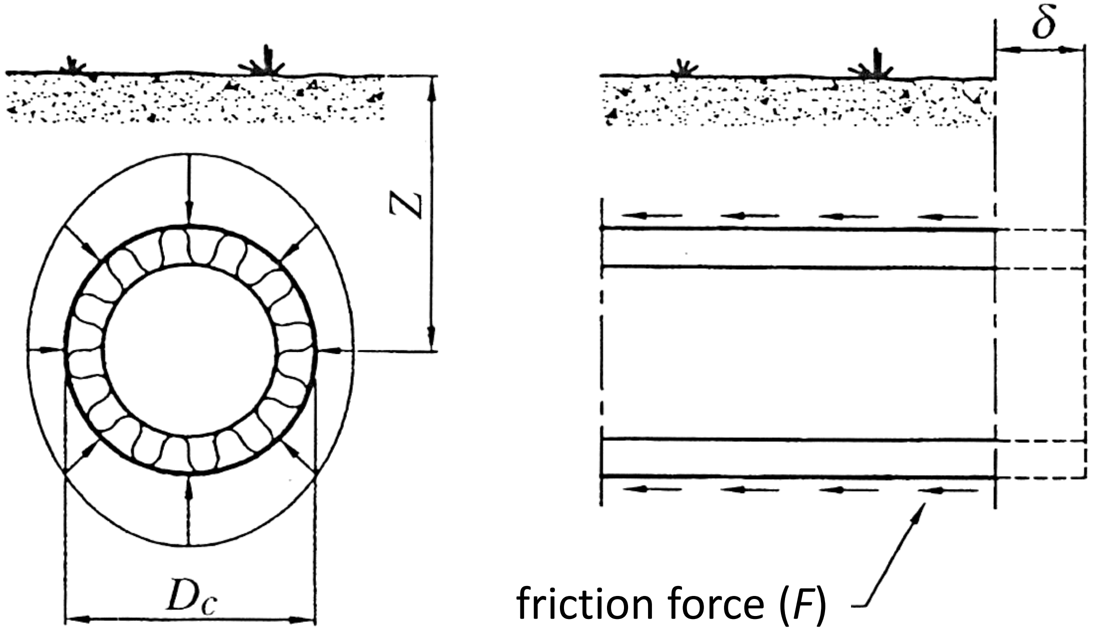
in the event of pipeline shifts, the pressure force caused by this pressure will produce a friction force equal to:

$$F = \pi \cdot D \cdot L \cdot p \cdot \mu \cdot 10^{-3}$$

Friction will counteract the movements of the pre-insulated pipeline, reducing displacement or hindering the possibility of free extension of the pipeline.

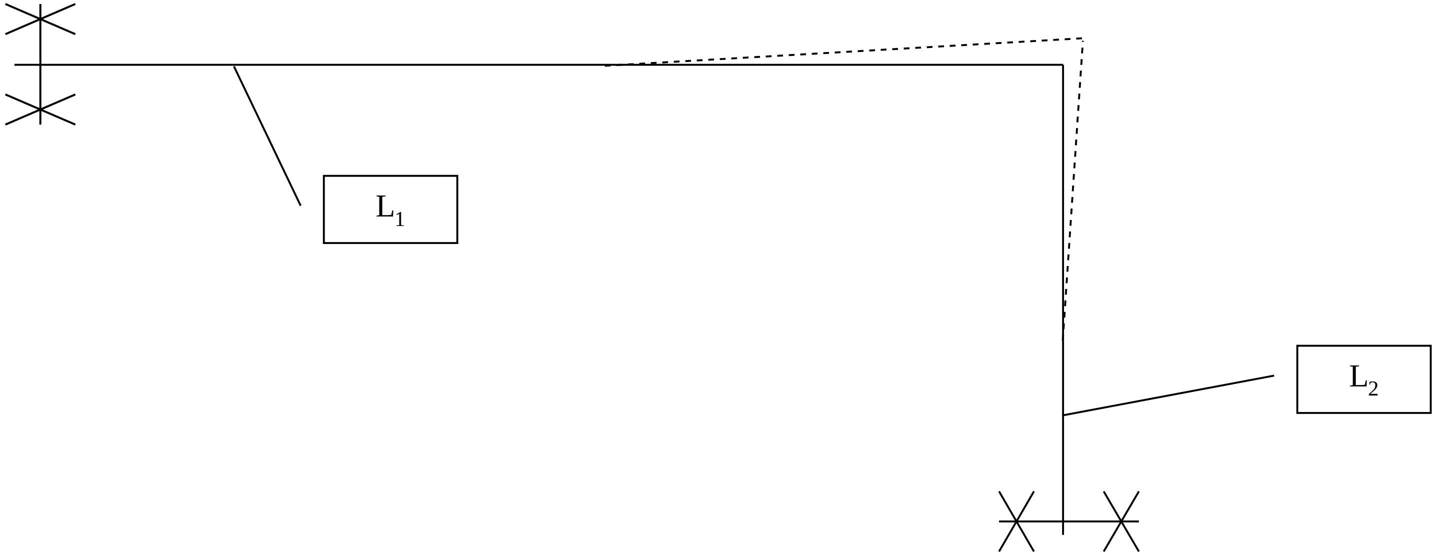
At a distance from the free end of the pipeline, called **the friction length**, the pipeline may not move at all because a kind of conventional fixed point (support) will be created.

Elongation compensation of pre-insulated pipes



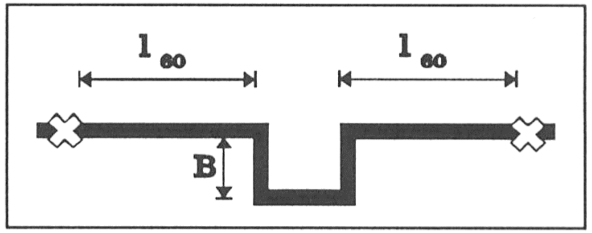
Soil pressure and friction force

Elongation compensation of pre-insulated pipes

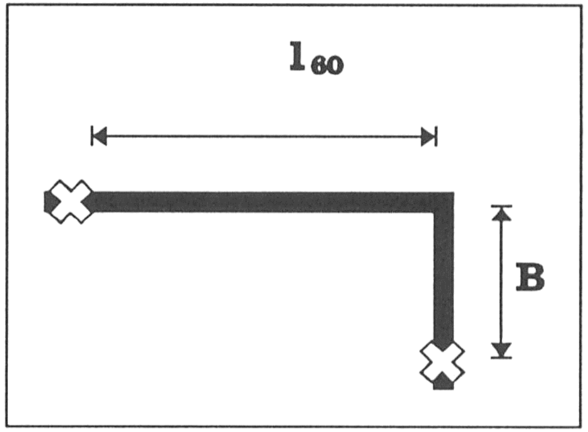


In preinsulated networks, can be compensated for thermal elongations using U-shaped, L or Z-shaped compensation. To make pipeline displacement in the ground possible, special foam spring pads are used or soil is removed from the pipeline displacement zone.

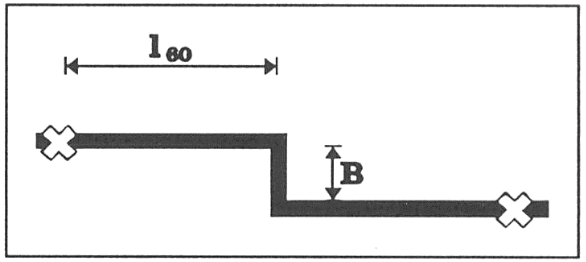
U-shaped compensation

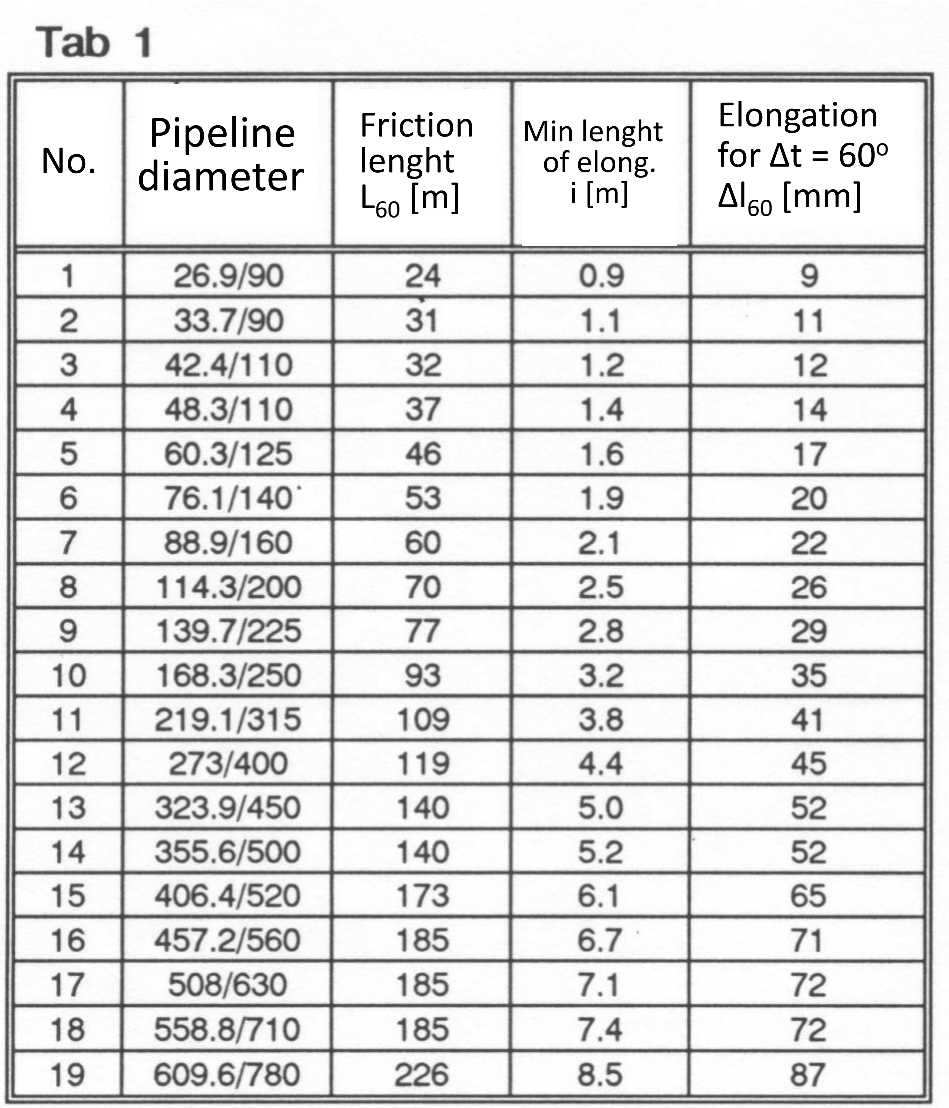


L-shaped compensation



Z-shaped compensation





Tab 1

No.	Pipeline diameter	Friction lenght L_{60} [m]	Min lenght of elong. i [m]	Elongation for $\Delta t = 60^o$ Δl_{60} [mm]
1	26.9/90	24	0.9	9
2	33.7/90	31	1.1	11
3	42.4/110	32	1.2	12
4	48.3/110	37	1.4	14
5	60.3/125	46	1.6	17
6	76.1/140	53	1.9	20
7	88.9/160	60	2.1	22
8	114.3/200	70	2.5	26
9	139.7/225	77	2.8	29
10	168.3/250	93	3.2	35
11	219.1/315	109	3.8	41
12	273/400	119	4.4	45
13	323.9/450	140	5.0	52
14	355.6/500	140	5.2	52
15	406.4/520	173	6.1	65
16	457.2/560	185	6.7	71
17	508/630	185	7.1	72
18	558.8/710	185	7.4	72
19	609.6/780	226	8.5	87

Elongation compensation of pre-insulated pipes

Traditional method, full compensation

Takeover of the elongation due to the friction of the surface of the casing pipe with the floor.

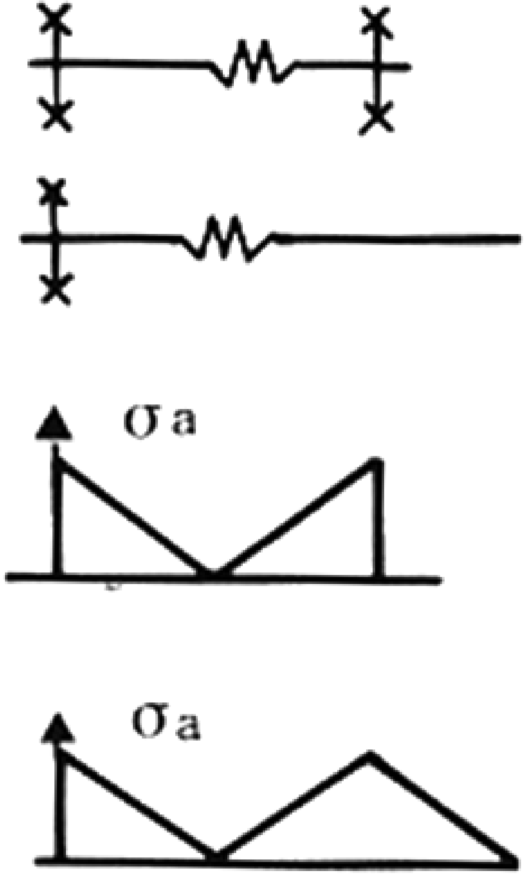
Installing and backfilling pipes is done in a cold state before bringing them to heat.

Compensation occurs through the use of axial compensators or compensating cables placed on straight sections. The distance between the compensators depends on the friction forces between the pipe and the soil in which the pipe has been laid.

The element that restrains elongation is the soil, that is the covering of the casing pipe.

Restraining the elongation depends on the friction force of the ground.

Maintenance and extension does not require cooling.



Stacking method 1 – total compensation

The friction force can be determined from the formula:

$$F = \pi \cdot D \cdot H \cdot \rho \cdot g \cdot \mu$$

The extension of the pipe after its covering can be calculated from the formula

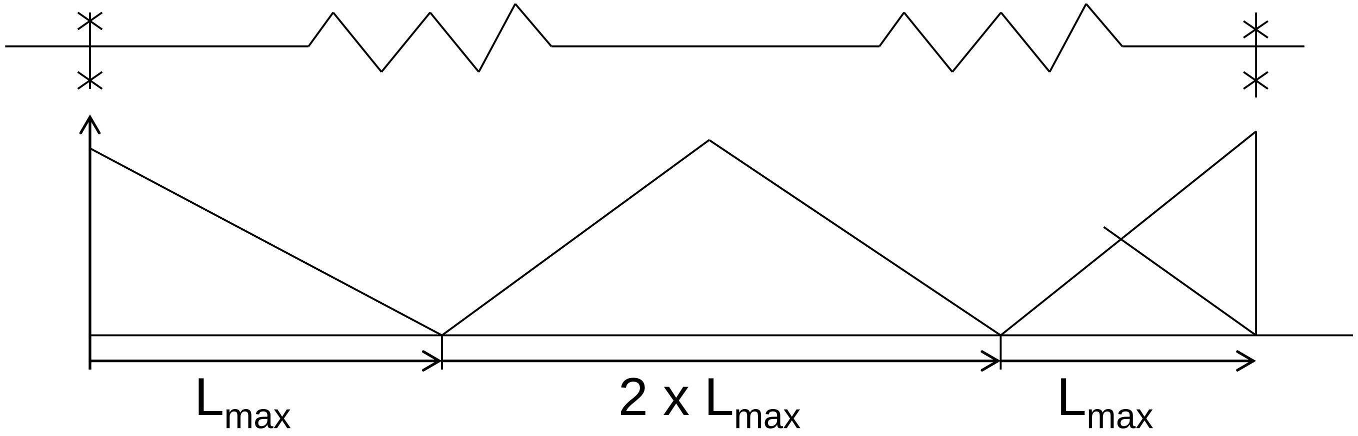
$$\Delta l = \alpha \cdot (t_{rob} - t_{mon}) - \frac{F \cdot L^2}{2 \cdot E \cdot A}$$

where the first part represents a free elongation and the second part a reduction in elongation corresponding to the effect of the ground. The formula does not take into account the influence of circumferential stresses originating from overpressure inside the pipe, because their influence is slight on elongation.

Layout method No. 1:
total compensation – installation distances

The friction forces increase with increasing distance from the point of elongation. The friction forces are transmitted by the compressive stresses in the pipe. At a given point of the pipe the stresses may exceed the allowable stresses. Permissible stress has a decisive influence on the distance between two elongating elements.

$$L_{\max} = \frac{\sigma_{dop}\,[\mathrm{N/mm^2}] \cdot A\,[\mathrm{mm^2}]}{F\,[\mathrm{N/m}]}$$



Elongation compensation of pre-insulated pipes

The pipes are heated in an open trench to the intermediate temperature between the assembly temperature and the working temperature.

The pipes can move freely, so lengthening elements need not to be used. After covering and heating to the working temperature, the stresses that will arise will be lower than the allowable stress.

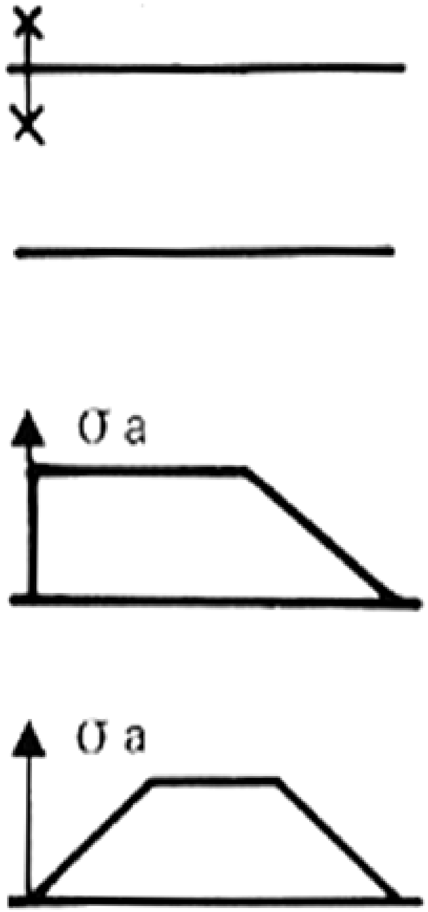
The binding elements of the outer parts of the casing pipe (sockets) must be emplaced.

Before covering, the pipe is preheated to the required temperature (pre-heating temp.).

The material filling the trench keeps the heat pipe in a horizontal and vertical position. The heat pipe can be uncovered only when its temperature is lower than the preheating temperaturę.

Expansion of the network – under special control.

With pre-heating



Elongation compensation of pre-insulated pipes – laying method No. 2: initial pre-tension

Heating can be done with heat from an existing system, by electricity or by the use of heated air.

At the initial thermal strain, it is necessary to strive that the compressive stresses at the working temperature and the stresses in the temperature of the cooling are balanced so that they do not exceed the permissible stresses at any point.

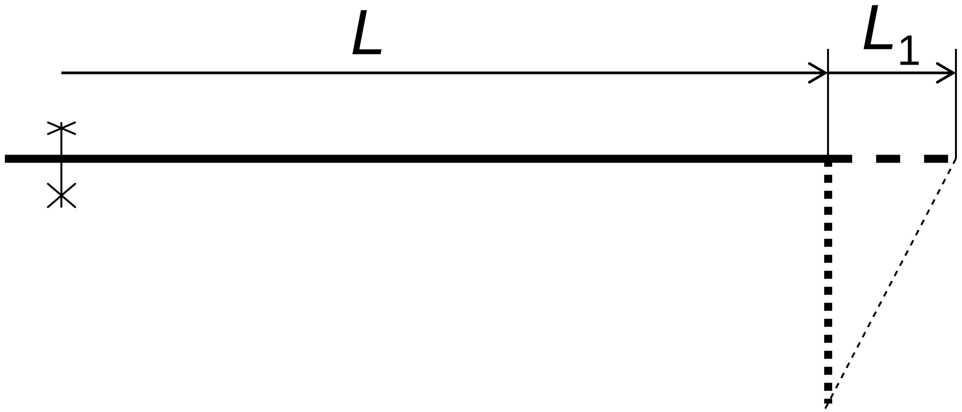
$$\sigma_{osiowe} = E \cdot \alpha \cdot \Delta t$$

Elongation compensation of pre-insulated pipes – laying method No. 2: initial pre-tension

The elongation of the ΔL_1 of the tube heated to the preheating temperature in an open trench is a free extension

During heating to the working temperature, the elongation is increased by the value of ΔL_2

$$\Delta L_1 = \alpha \cdot (t_{pod.wst} - t_{mont}) \cdot L$$



Then the pipes are covered

Elongation compensation of pre-insulated pipes

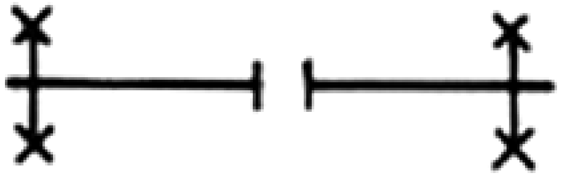
Here, the elongation between the casing and the mantle is taken over. The friction force must be known.

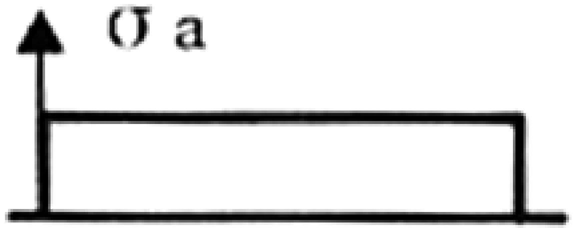
The binding elements of the outer parts of the casing pipe (sockets) must be emplaced.

Covering takes place in the cold state. Only the exposed place (2–3 m) is left for the "START-UP" initial compensator. Compensation of the compensator occurs after pre-heating, insulating and backfilling.

The material filling the trench keeps the heat pipe in a horizontal and vertical position.
Uncovering may occur at the preheating temperature.
Expansion of the network – under special control.

With the use of disposable compensators

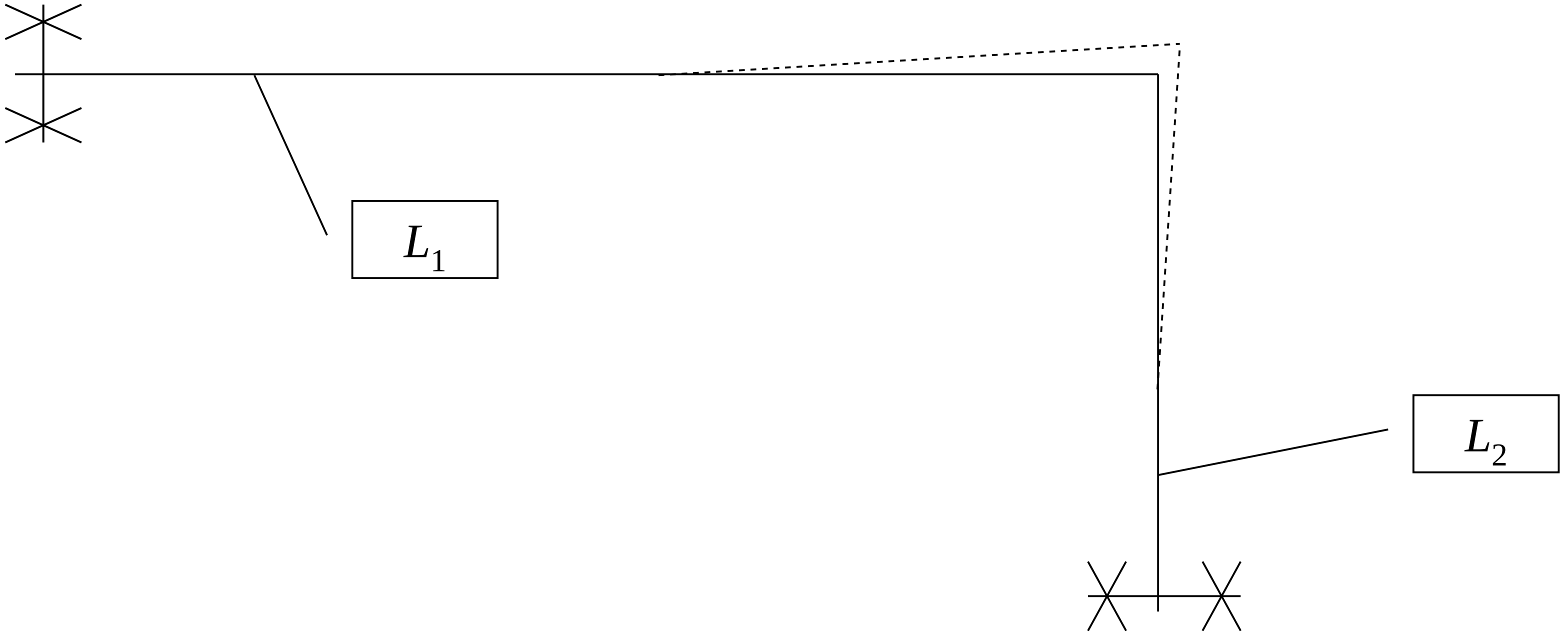




Elongation compensation of pre-insulated pipes

- Cold assembly ABB.
- Long sections are freely laid without any compensation for elongation. In this case, it is assumed that after several heating and cooling cycles, the stresses in the pipeline reach equilibrium.

Calculate the deformation of the compensation knee as in the figure (Arm lengths L_1 = 30 m and L_2 = 15 m, respectively).



Length of the deformable arm (length of the compensation zone)

$$L_A = \sqrt{\frac{1.5 * E}{\sigma_{dop}} * d * \Delta L}$$

$$L_{A1} = \sqrt{\frac{1.5 * E}{\sigma_{dop}} * d * \Delta L_2}$$

$$L_{A2} = \sqrt{\frac{1.5 * E}{\sigma_{dop}} * d * \Delta L_1}$$

$E = 2 * 10^{11}$ Pa

$\Delta L_1 = 0.0345$ m

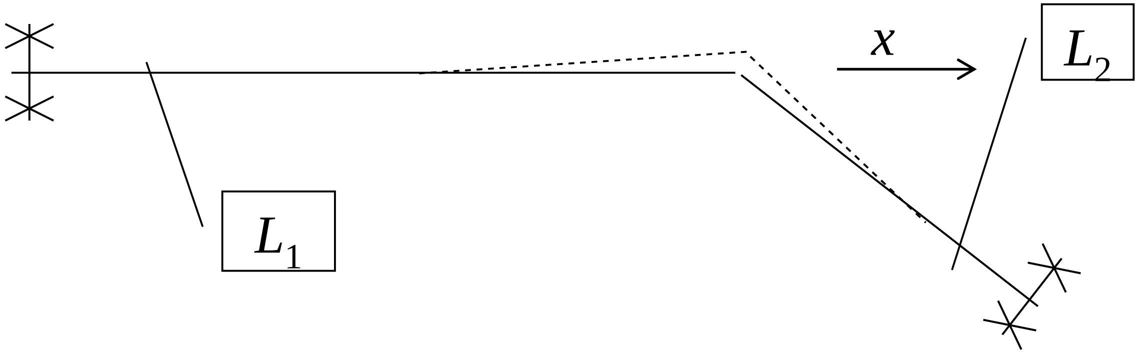
$\Delta L_2 = 0.0195$ m

$d = 0.108$ m

$$L_{A1} = \sqrt{\frac{1.5 * 2 * 10^{11}\ \text{Pa}}{150 * 10^{6}\ \text{Pa}} * 0.108\ \text{m} * 0.0195\ \text{m}} = 2.05\,\text{m}$$

$$L_{A2} = \sqrt{\frac{1.5 * 2 * 10^{11}\ \text{Pa}}{150 * 10^{6}\ \text{Pa}} * 0.108\ \text{m} * 0.0345\ \text{m}} = 2.73\ \text{m}$$

Example as above, except that the arms form an angle of 135°



$$L_{A1}=\sqrt{\frac{1.5*E}{\sigma_{dop}}*d*W_x}$$

$$W_x=\frac{\Delta L_y}{tg\varphi}+\frac{\Delta L_x}{\sin\varphi}$$

$$L_{A2}=\sqrt{\frac{1.5*E}{\sigma_{dop}}*d*W_y}$$

$$W_y=\frac{\Delta L_x}{tg\varphi}+\frac{\Delta L_y}{\sin\varphi}$$

Example with arms forming an angle of 135°

$$W_x = \frac{\Delta L_2}{\operatorname{tg}\varphi} + \frac{\Delta L_1}{\sin\varphi} = \frac{0.0195\ \mathrm{m}}{\operatorname{tg}45^\circ} + \frac{0.0345\ \mathrm{m}}{\sin 45^\circ} = 0.0195\ \mathrm{m} + 0.0488\ \mathrm{m} = 0.0683\ \mathrm{m}$$

$$W_y = \frac{\Delta L_1}{\operatorname{tg}\varphi} + \frac{\Delta L_2}{\sin\varphi} = \frac{0.0345\ \mathrm{m}}{\operatorname{tg}45^\circ} + \frac{0.0195\ \mathrm{m}}{\sin 45^\circ} = 0.345\ \mathrm{m} + 0.0276\ \mathrm{m} = 0.0621\ \mathrm{m}$$

$$L_{A1} = \sqrt{\frac{1.5 * 2 * 10^{11}\ \mathrm{Pa}}{150 * 10^{6}\ \mathrm{Pa}} * 0.108\ \mathrm{m} * 0.0683\ \mathrm{m}} = 3.84\ \mathrm{m}$$

$$L_{A1} = \sqrt{\frac{1.5 * 2 * 10^{11}\ \mathrm{Pa}}{150 * 10^{6}\ \mathrm{Pa}} * 0.108\ \mathrm{m} * 0.0621\ \mathrm{m}} = 3.66\ \mathrm{m}$$

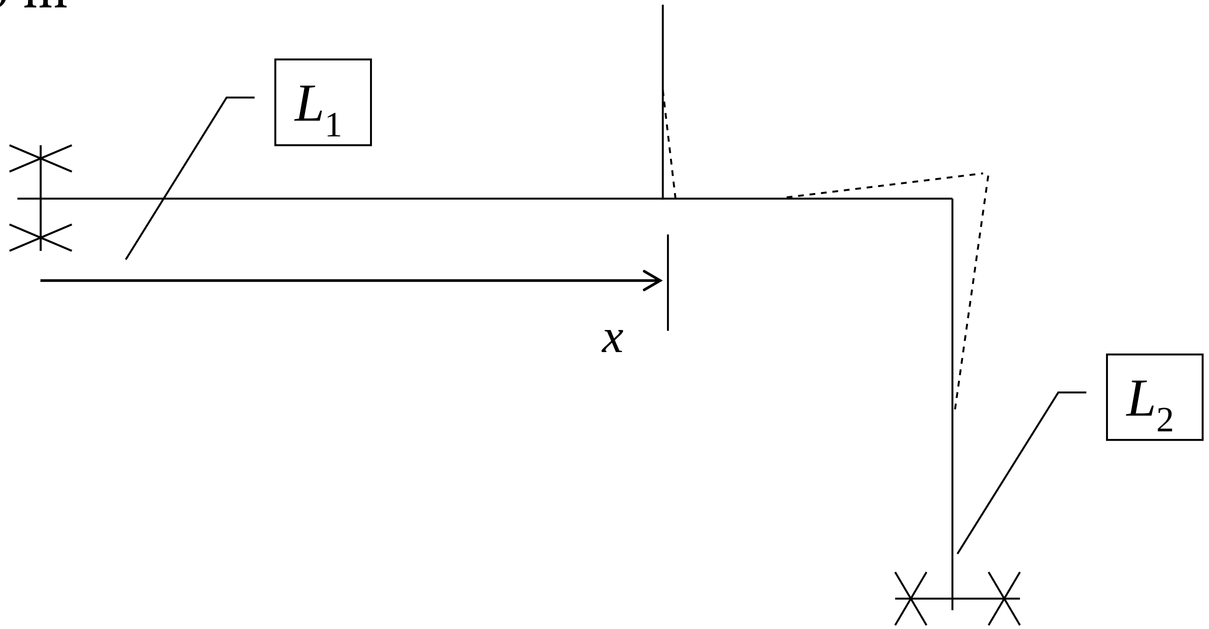
Side shift of the network branch

$$\Delta L_x = \alpha \cdot (T_1 - T_2) \cdot x + \frac{1}{E} \cdot (0.5 - \nu) \cdot \frac{p \cdot (d - s)}{2 \cdot s} \cdot x - \frac{F_t \cdot x^2}{2 \cdot E \cdot A_{st}} =$$

$$= 1.2 \cdot 10^{-5} 1/\mathrm{K} \cdot (130°\mathrm{C} - 10°\mathrm{C}) \cdot 20\ \mathrm{m} +$$

$$+ \frac{1}{2 \cdot 10^{11}\ \mathrm{Pa}} \cdot (0.5 - 0.27) \cdot \frac{6 \cdot 10^5\ \mathrm{Pa} \cdot (0.108\ \mathrm{m} - 0.004\ \mathrm{m})}{2 * 0.004\ \mathrm{m}} \cdot 20\ \mathrm{m} -$$

$$- \frac{\left(5.190 \frac{\mathrm{N}}{\mathrm{m}}\right) \cdot (20\ \mathrm{m})^2}{2 \cdot 2 \cdot 10^{11}\ \mathrm{Pa} \cdot 0.001306\ \mathrm{m}^2}$$



Selection of compensators

Select a compensator for a pre-insulated pipe supported by fixed points located at a distance of 60 m.

- The total elongation of one segment (from the fixed point to the compensator) is ΔL_1 = 0.0345 m
- Axial compensator
- The total compensation capacity of the axial compensator should be:

$$\Delta L_K = 2 * \Delta \boldsymbol{L_1} = 2 * 0.0345 \text{ m} = 0.069 \text{ m}$$

- U-shaped compensator

The lenght of the U-compensator:

$$W = 0.7 * \sqrt{\frac{1.5 * E * d * \Delta L_1 * C}{\sigma_{dop}}} = 0,7 * \sqrt{\frac{1.5 * 2 * 10^{11} \text{ Pa} * 0.108 \text{ m} * 0.0345 \text{ m} * 1}{150 * 10^6 \text{ Pa}}} = 1.91 \text{ m}$$

C – shape factor (includes pipe bending radius)

Strength calculations
Basics of strength calculations of thermal networks

Thermal elongation of a freely supported steel pipe heated from temperature T_1 to T_2

$$\Delta L_t = \alpha * (T_2 - T_1) * L$$

$$\Delta L_t = 1.2 * 10^{-5} 1/K * (130°\mathrm{C} - 10°\mathrm{C}) * 30\,\mathrm{m} = 0.0432\ \mathrm{m} \rightarrow (4.32\ \mathrm{cm})$$

Elongation of the steel pipe caused by the increase of internal pressure (pipe leading the medium under pressure *p*)

$$\Delta L_p = \frac{1}{E} * (0.5 - \nu) * \frac{p * (d - s)}{2 * s} * L$$

$$\Delta L_p = \frac{1}{2 * 10^{11}\ \mathrm{Pa}} * (0.5 - 0.27) * \frac{6 * 10^5\ \mathrm{Pa} * (0.108\ \mathrm{m} - 0.004\ \mathrm{m})}{2 * 0.004\ \mathrm{m}} * 30\,\mathrm{m} =$$

$$= 0.000269\ \mathrm{m} \rightarrow 0.27\,\mathrm{mm}$$

The resultant elongation of a pre-insulated pipe preheated from temperature T_1 to T_2, with the pressure p

$$\Delta L = \Delta L_t + \Delta L_p - \Delta L_F = \alpha * (T_1 - T_2) * L + \frac{1}{E} * (0.5 - \nu) * \frac{p * (d - s)}{2 * s} * L - \frac{F_t * L^2}{2 * E * A_{st}}$$

Where:

ΔL_t – thermal

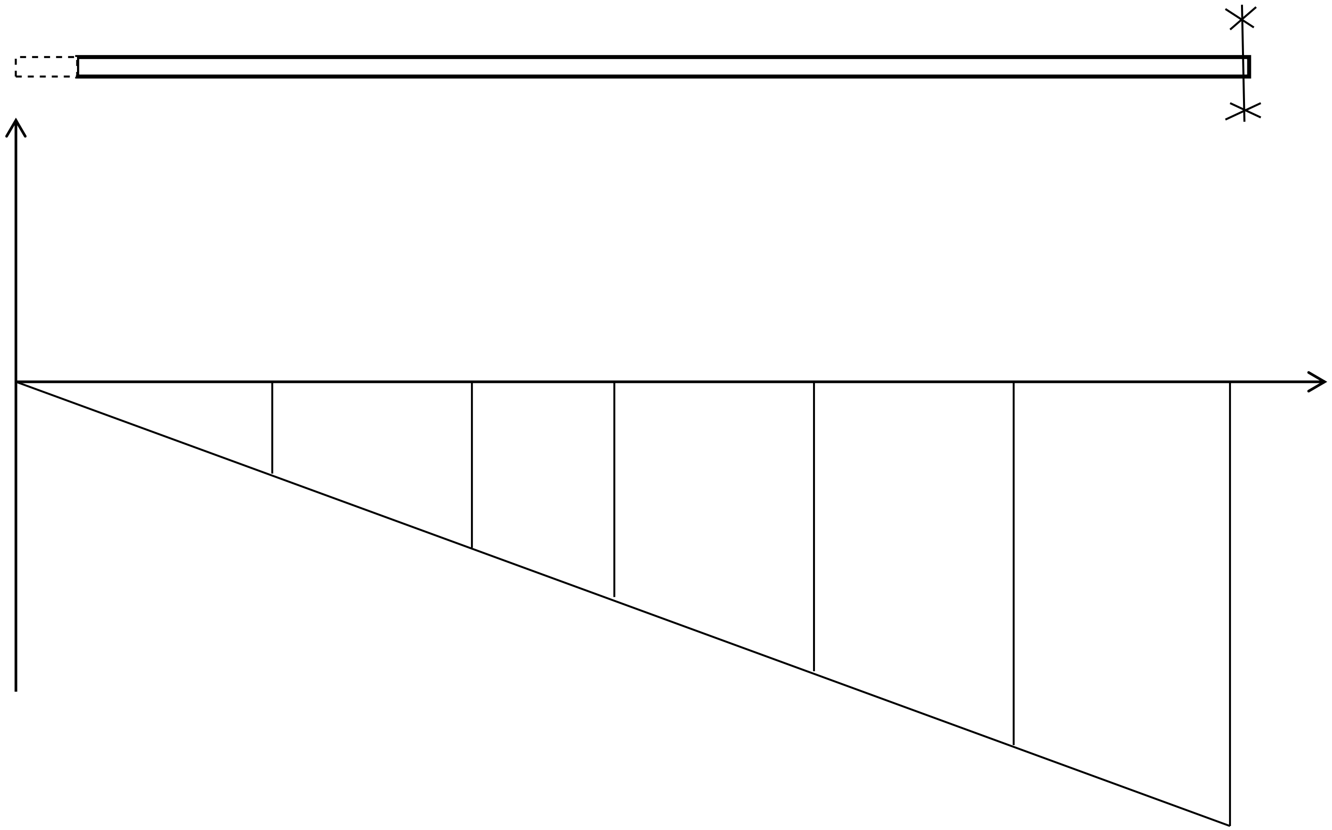
ΔL_p – pressure

ΔL_F – friction

A_{st} – cross-section area of the steel pipe

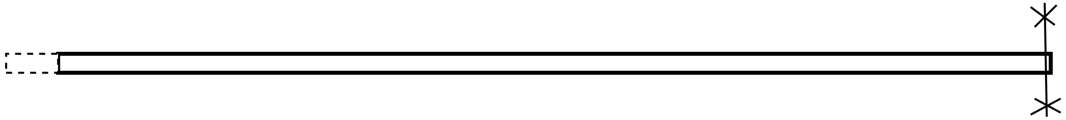
E – Young module (200,000 MPa)

Compression stress in the pipe – one of the ends of the pipe permanently fixed to the ground



Example

Calculate the resultant extension of the pre-insulated pipe and the distribution of the compressive stresses if it is covered with sand of 1.5 kg /dm^3 density. The pipe has insulation with an outer diameter of 208 mm. One of the ends of the pipe permanently attached to the base (fixed point). Other data as in previous examples.



$$\Delta L = \Delta L_t + \Delta L_p - \Delta L_F = 0.0432\ \mathrm{m} + 0.000269\ \mathrm{m} - \frac{F_t * L^2}{2 * E * A_{st}}$$

$$F_t = \mu * \pi * D * \rho * g * h * \left(\frac{1+K_o}{2}\right)$$

$$F_t = 0.4 \cdot 3.14 \cdot 0.208\ \mathrm{m} \cdot 1800\ \frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 9.81 \frac{\mathrm{m}}{\mathrm{s}_2} \cdot 1.5\ \mathrm{m} \cdot \left(\frac{1+0.5}{2}\right) = 5190\ \mathrm{N/m}$$

$$A_{st} = \frac{\pi}{4}\left[d^2 - (d-2s)^2\right] \approx \pi * (d-s) * s$$

Example: cont.

$$\Delta L = \Delta L_t + \Delta L_p - \Delta L_F = 0.0432\ \text{m} + 0.000269\ \text{m} - \frac{\left(5{,}190\frac{\text{N}}{\text{m}}\right)\cdot(30\ \text{m})^2}{2\cdot 2\cdot 10^{11}\ \text{Pa}\cdot 0.001306\,\text{m}^2} =$$

$$= 0.0432\,\text{m} + 0.000269\ \text{m} - 0.009\ \text{m} = 0.0345\ \text{m}$$

$$A_{st} \approx 3.14 * (0.108\ \text{m} - 0.004\ \text{m}) * 0.004\ \text{m} = 0.001306\ \text{m}^2$$

Compressive stress in the pipe:

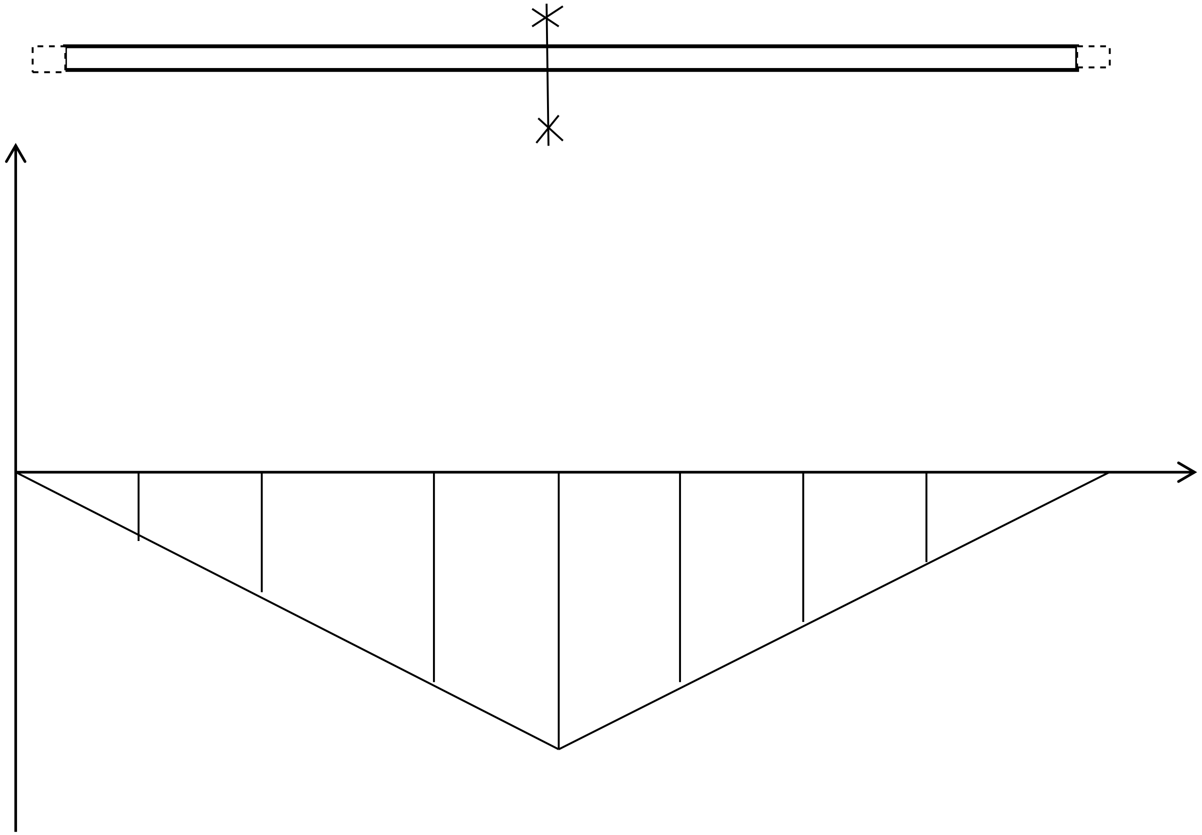
At the free end:

$$\sigma_{x=O} = 0$$

At a fixed point:

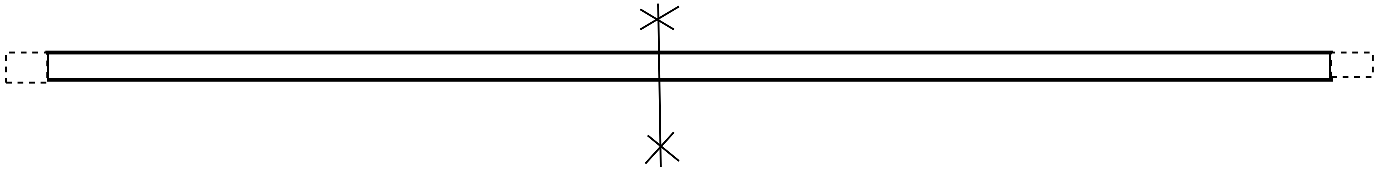
$$\sigma_{x=L} = \frac{F_t \cdot x}{A_{st}} = \frac{5{,}190\frac{\text{N}}{\text{m}}\cdot 30\,\text{m}}{0.001306\ \text{m}^2} \approx 119{,}220{,}000\ \text{Pa} = 119.22\ \text{MPa}$$

Compression stress in the pipe assuming that the pipe can freely extend in both directions



Example

Calculate the resultant extension of the pre-insulated pipe as in the previous example and the distribution of compressions, assuming that the pipe can be freely extended in both directions (in the center, a neutral point is created – a fixed point).



$$\Delta L_t = 1.2 * 10^{-5} 1/\text{K} * (130°\text{C} - 10°\text{C}) * 15\ \text{m} = 0.0216\ \text{m} \rightarrow (2.16\ \text{cm})$$

$$\Delta L_p = \frac{1}{2 * 10^{11}\ \text{Pa}} * (0.5 - 0.27) * \frac{6 * 10^5\ \text{Pa} * (0.108\ \text{m} - 0.004\ \text{m})}{2 * 0.004\ \text{m}} * 15\ \text{m} =$$

$$= 0.000135\ \text{m} \rightarrow 0.135\ \text{mm}$$

$$\Delta L = \Delta L_t + \Delta L_p + \Delta L_F = 0.0216\text{m} + 0.000135\text{m} - \frac{\left(51{,}90 \frac{\text{N}}{\text{m}}\right) * (15\text{m})^2}{2 \cdot 2 \cdot 10^{11}\ \text{Pa} \cdot 0.001306\ \text{m}^2} =$$

$$= 0.0216\ \text{m} + 0.000135\ \text{m} - 0.0022\ \text{m} = 0.0195\ \text{m}$$

Total change in pipe length

$$\Delta L \;= 2 * \Delta L_i = 2 * 0.0195 \text{ m} = 0.039 \text{ m} \rightarrow (3.9 \text{ cm})$$

Compressive stress in the pipe:
At the ends:

$$\sigma_{x=0} = \sigma_{x=L} = 0$$

In the middle of the pipe:

$$\sigma_{x=1/2L} = \frac{F_t \cdot x}{A_{st}} = \frac{5{,}190 \,\frac{\text{N}}{\text{m}} \cdot 15\,\text{m}}{0.001306 \text{ m}^2} \approx 59{,}610{,}000\,\text{Pa} = 59.61 \text{ MPa}$$

Installation length – maximum distance of the end of the free section or ending with a compensating element (a knee or compensator) from the actual or contractual fixed point so selected that the compressive stress at the fixed point does not exceed the limit value (150 MPa for steel pipes).

$$\frac{F_t * x}{A_{st}} \leq \sigma_{dop} \rightarrow L_{\max} = \frac{\sigma_{dop} * A_{st}}{F_t}$$

$$L_{\max} = \frac{\sigma_{dop} \cdot A_{st}}{F_t} = \frac{150 \cdot 10^6 \text{ Pa} \cdot 0.001306 \text{ m}^2}{5{,}190 \frac{\text{N}}{\text{m}}} = 37.7 \text{ m}$$

- A_{st} – cross-section area of the steel pipe

Part 6

Substations

Thermal knots

A heat substation is a **set of various types of devices** that **supply** heat to the building and **connect** the external heat network with the internal installation. The task of the heat center is to **supply** heat from the grid to the recipient and **adjust** the thermal power drawn from the medium from the network **to the current demand** of the installation.

The node has a set of valves that **cut off the flow** of carrier from the network and heating system, devices for its **cleaning**, **parameter changes**, as well as **measuring** and **control** apparatus. There are several criteria and ways to classify thermal knots.

Substations

We divide the nodes due to their functions into:

- central heating nodes,
- central hot water nodes,
- technological heat nodes (ventilation),
- nodes for industrial use.

Due to the number of degrees of heating water:

- single-stage,
- two-stage.

Substations

According to the connection method of heat exchangers relative to heating:

- serial,
- in parallel,

in the case of a two-stage system – serial-parallel.

According to the type of equipment used for preparing and storing hot water:

- storageless, (without storage),
- with the storage.

Due to the number of simultaneously performed functions:

- single-function,
- dual-function eg heating (c.o) + domestic hot water (c.w.u.),
- multifunctional.

Thermal knots

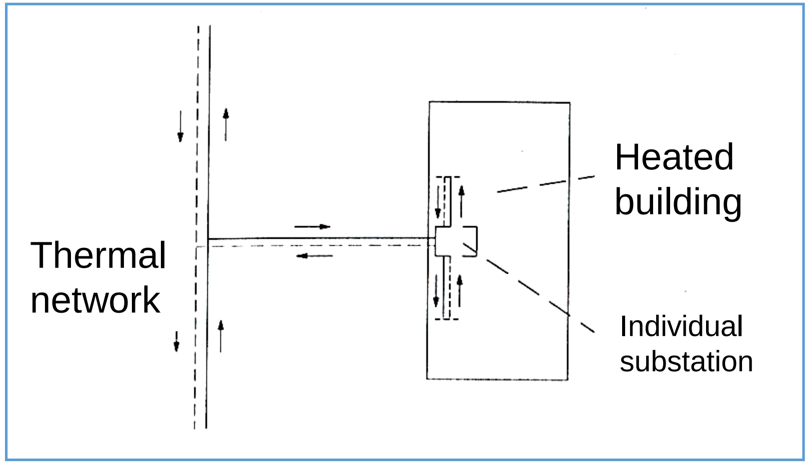
Thermal knots usually supply the building with heat. Sometimes there are several nodes in one building, constituting a source of heat for several installations such as heating, domestic hot water installations, ventilation and air conditioning systems in repetitive parts (segments) of the same building.

In this case, the substation is a **boundary element** between the district heating network and the internal installation in the building.

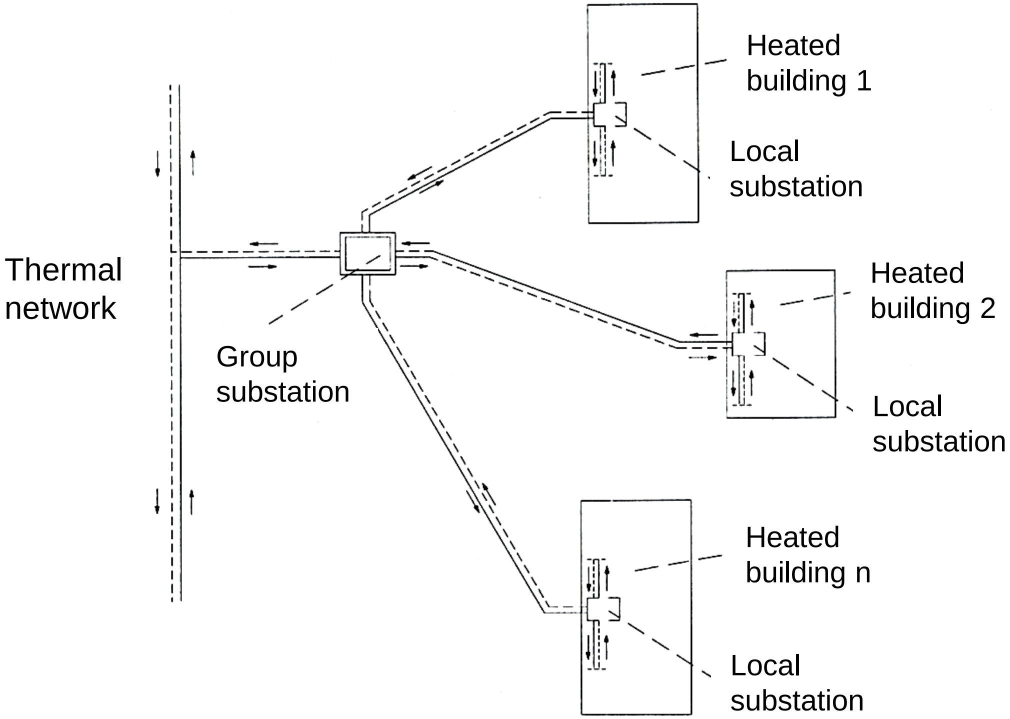
Substations

The substation can be located **inside** a heated object or appear as a **separate building**. Formerly, the so-called group nodes constituted the energy consumption system included in the high-performance medium (from the high-parameter network) and converting it to the level of the medium circulating in the low-parameter network, supplying several or a dozen or so buildings. The group heat substation then separates two types of heating networks. Currently, systems are being built in which the heat center is located only in a single flat (housing nodes).

Individual and group substations



Individual heat center



Group heat center

Due to the location, thermal centers can be divided into:

- Built-in heating nodes (in a building for other purposes, as compact or made at the construction site),
- Free standing heating nodes (constituting a separate building, usually executed at the construction site).

Depending on the number of heated buildings (in Polish conditions), thermal centers are divided into:

- Individual heat centers,
- Group heat centers (heating a group of buildings).

In the EU countries, a division into nodes is additionally introduced depending on the type of a residential building, for:

- heat centers in single-family buildings,
- heat centers in multi-family buildings.

Substations

In terms of the number of functions performed, thermal nodes can be divided into:

- Single-function nodes:
  - ✓ central heating,
  - ✓ technological heat,
  - ✓ central hot water (only in boiler rooms).

Thermal nodes

- Two-function nodes:
  - ✓ central heating and technological heat,
  - ✓ central heating and domestic hot water,
  - ✓ technological heat and domestic hot water.

- Three-function nodes (multifunctional)
  - ✓ central heating, technological heat and domestic hot water.

Thermal nodes

The node has the following devices:

- to cut off the inflow of the medium,
- for its purification (filters),
- to change the parameters of the medium,
- measuring and controlling.

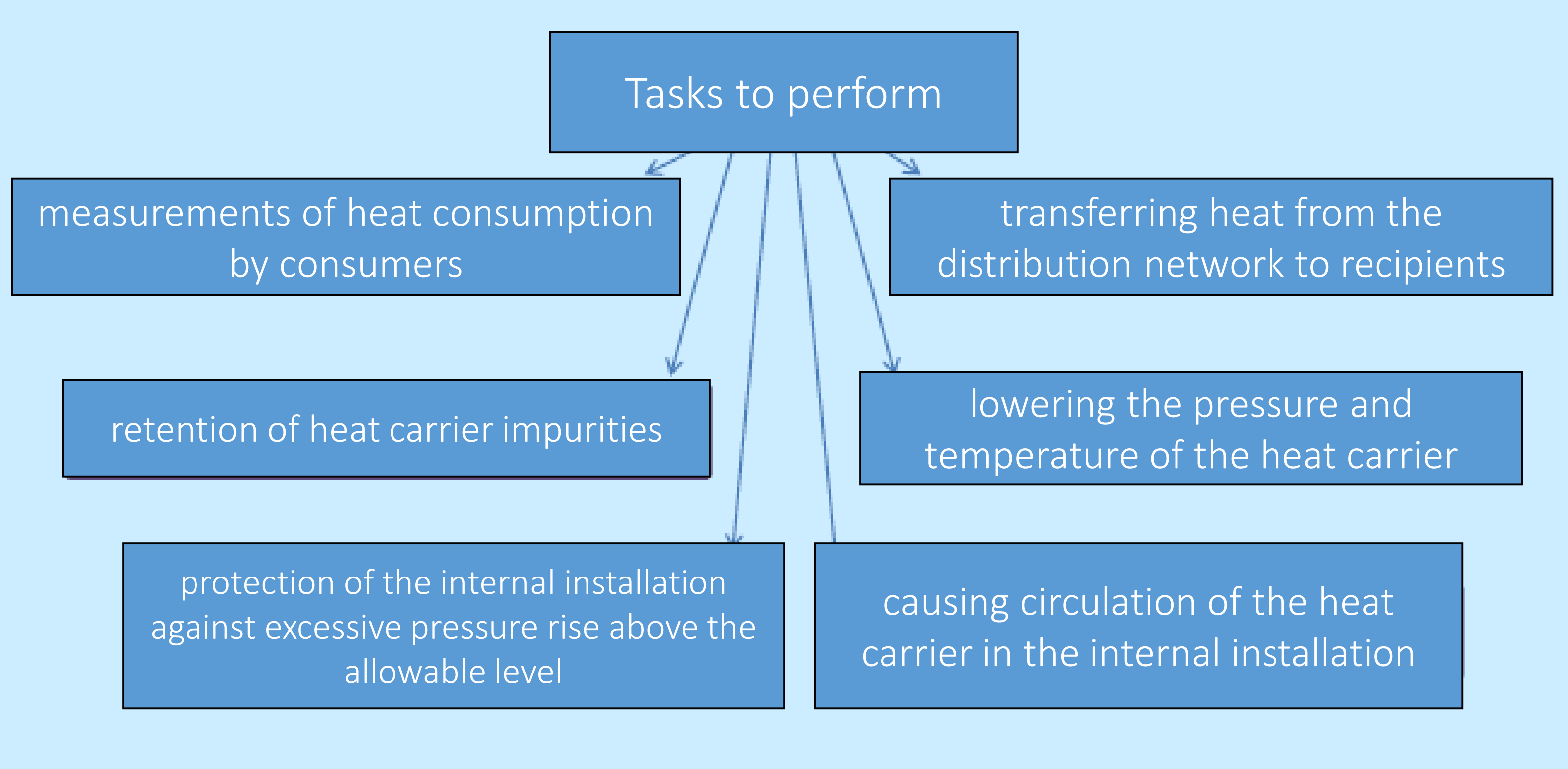
Thermal nodes

Thermal centers – designed for distribution of heat carriers and possible adjustment of their parameters, flowing to individual receivers or their groups.

Types of heat substations:

- water heat substations,
- steam heat substations.

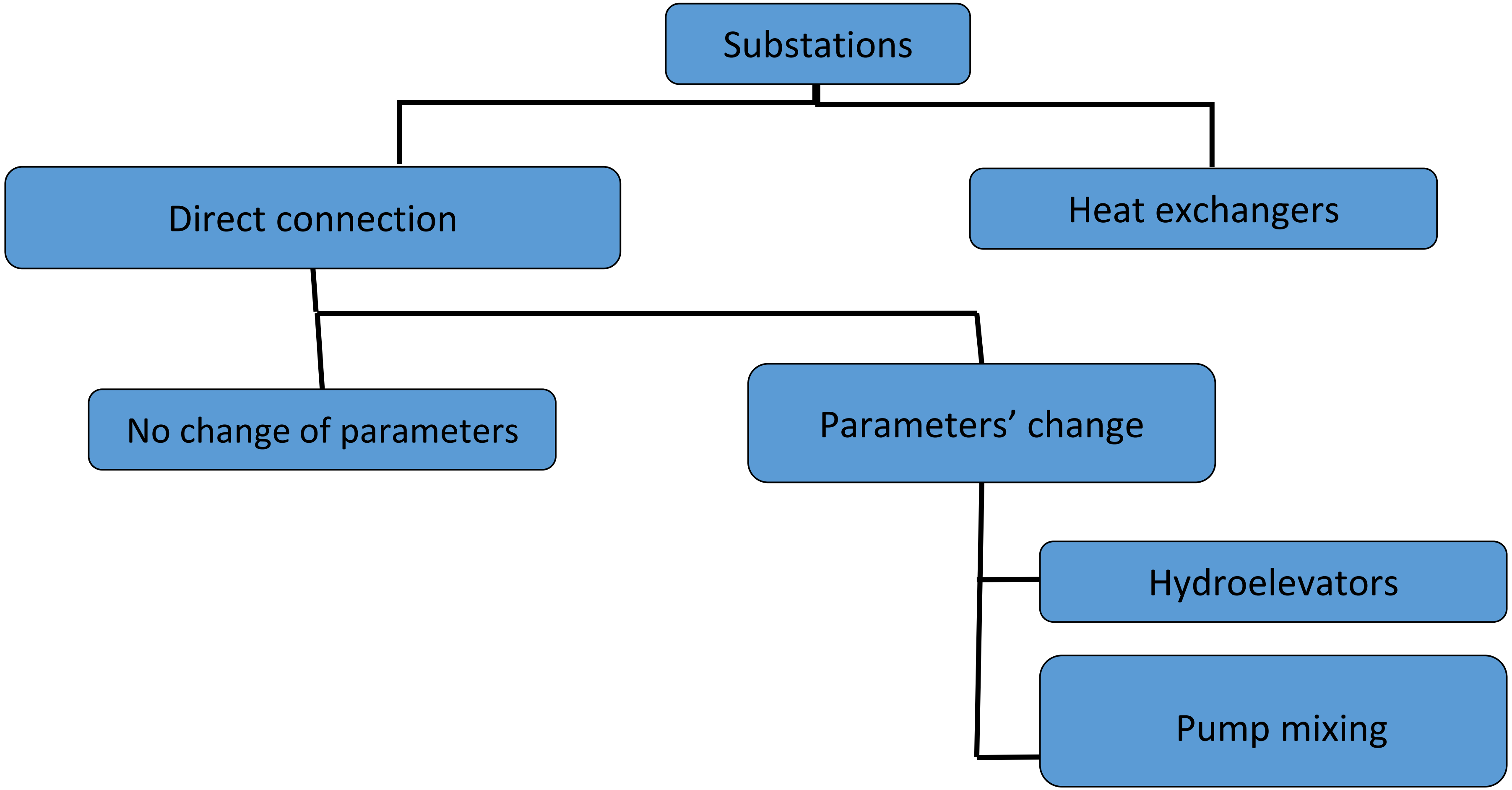
Thermal nodes – tasks



Tasks to perform

- measurements of heat consumption by consumers
- transferring heat from the distribution network to recipients
- retention of heat carrier impurities
- lowering the pressure and temperature of the heat carrier
- protection of the internal installation against excessive pressure rise above the allowable level
- causing circulation of the heat carrier in the internal installation

Classification of heat substations in terms of connection method



The division in terms of the method of connecting the substation

- direct connection (direct nodes),
- indirect connection (heat exchangers).

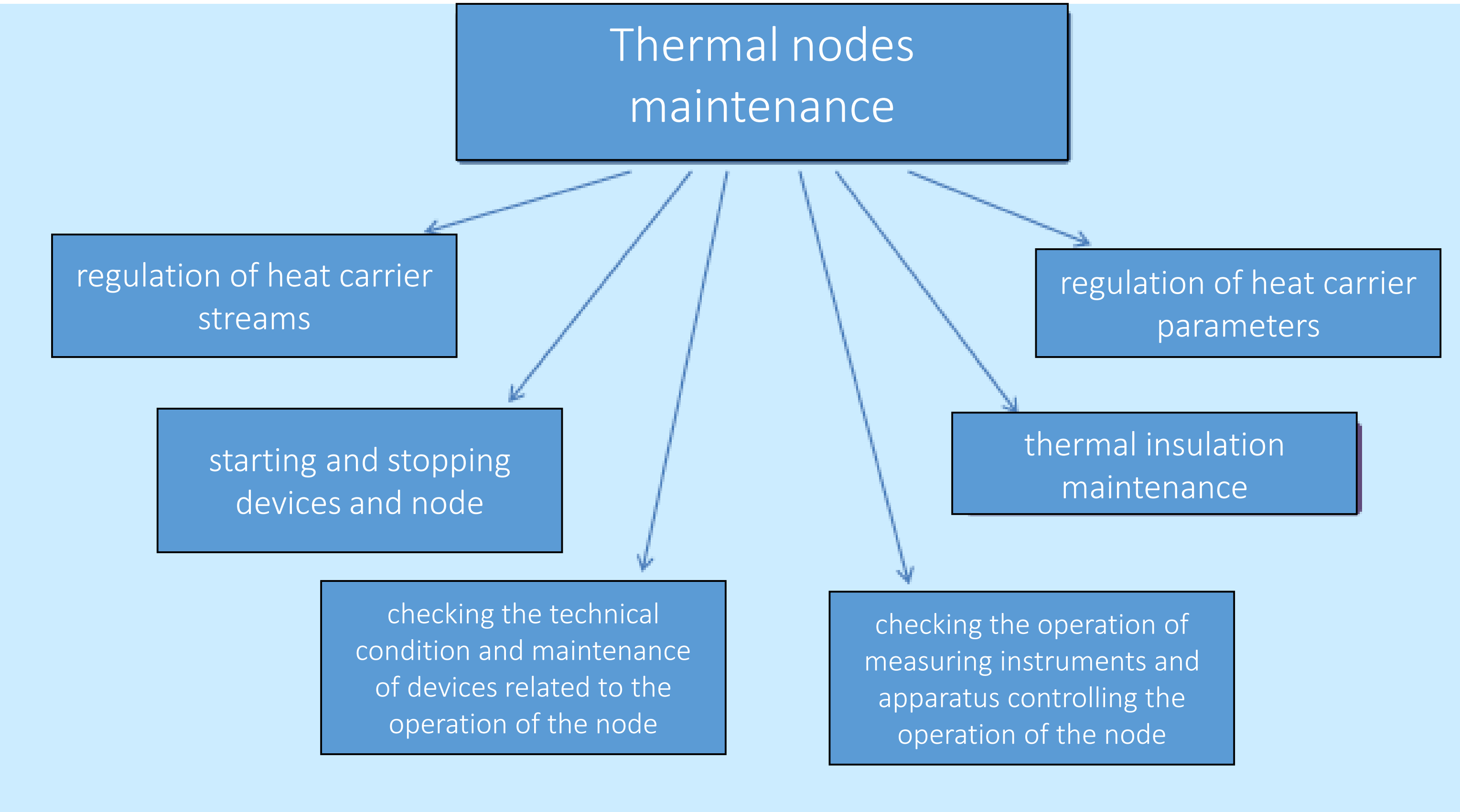
Direct nodes can be divided into:

- nodes without parameter transformation,
- nodes with parameter transformation.

Special cases of nodes with parameter transformation are:

- hydroelevators nodes,
- pump mixing nodes.

Thermal nodes – maintenance



Thermal nodes maintenance

regulation of heat carrier streams

starting and stopping devices and node

checking the technical condition and maintenance of devices related to the operation of the node

checking the operation of measuring instruments and apparatus controlling the operation of the node

thermal insulation maintenance

regulation of heat carrier parameters

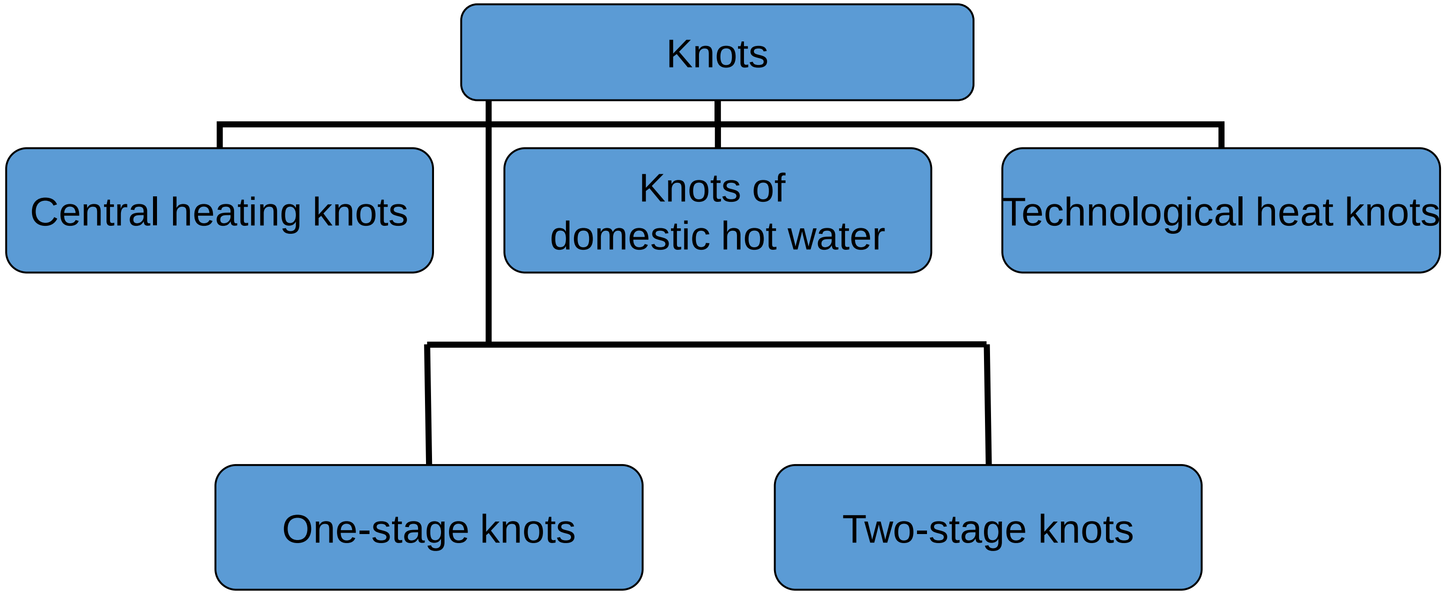
Functions of the substation

- **Delivery and transformation** of heat from the heating network to the installation,
- **Measurement** of heat consumption for billing purposes,
- Automatic **temperature control** in secondary circuits,
- Automatic **adjustment** of the available differential **pressure**.

Optional functions:

- **Registering** basic parameters,
- Enabling **remote communication**,
- Facilitating heat carrier **change** in temperature and pressure.

Classification of substations in terms of their functions



Knots

Central heating knots

Knots of domestic hot water

Technological heat knots

One-stage knots

Two-stage knots

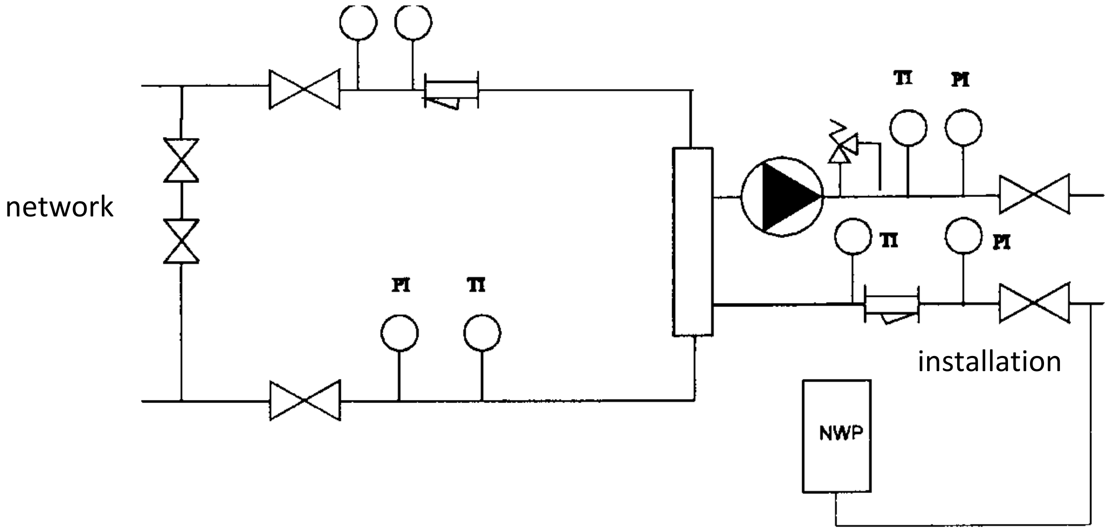
Thermal substations

An important element of the knot is a **heat exchanger**, a device in which the heat is transferred from the heating medium flowing in the network to the heating medium supplying the internal installation.

In the heat exchangers, therefore, another medium circulates in the network, another in the installation. Therefore, there are no disadvantages resulting from the direct connection of hydraulic systems, and in some unfavorable pressure configurations in the network leading to the emergence of emergency states. The pressure distribution in the system is completely separated from the system of pressures in the network, both during operation and "parking".

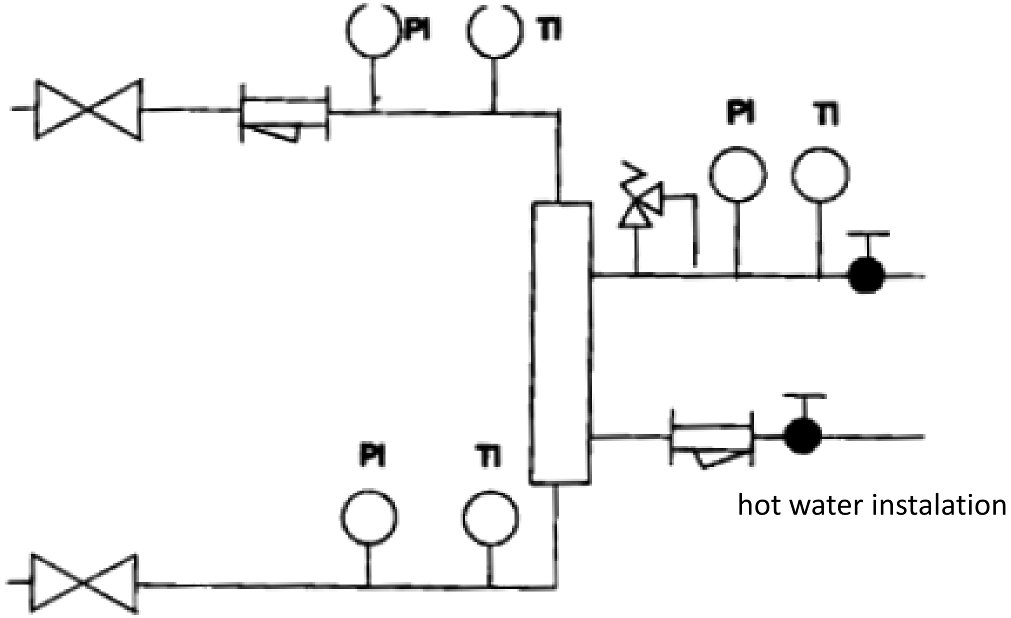
The design parameters (temperatures) of the primary circuit are the network parameters, and the secondary circuit refers to the installation. The temperature of water returning to the network is higher than the temperature of water returning from the installation. The difference between the design and actual temperature of water returning to the grid depends on the characteristics of the heat exchangers used: for some types – larger for others – smaller. The size of this difference affects the temperature efficiency of heat exchange.

Single-functional knots for central heating and process heat



The exchanger units preparing the heating medium for central heating and process heat are similar to each other in terms of the connection diagram. Primary and secondary sides are generally fitted with shut-off valves, manometers and thermometers. An indispensable element of the knot for central heating and process heat is a circulation pump. On the secondary side of the node with the closed system of protection against pressure rise, a safety valve should be installed. The safety valve at the membrane expansion vessel is an element necessary if the product of overpressure (bar) and total capacity (in dm^3) the vessel is larger than 300. This is due to the Polish regulations of Technical Supervision.

Single-functional nodes for the preparation of domestic hot water



Exchange units for central heating of hot water rarely appear as independent objects, usually connected to a central heating node, direct or indirect. As separate, they are mainly used in low parameter boiler rooms.

Multifunctional nodes

- Exchangers with individual functions form in complex types of nodes, so-called **sections or connectors**.
- The sections (joints) of central heating and central hot water are equipped with fittings and **automatic control** devices, according to the type of node chosen. Certain equipment will be in the single-stage one-stage heat source preparation, other types in two-stage.
- In a node with combined central heating and central hot water functions there are two ways of installing heat exchangers: **serial and parallel**.

Multifunctional nodes

- A series connection means that the medium (all or part of the mass flow of the medium) flows sequentially (in series) through the appropriate sections: central heating and hot water.
- The branch of the medium for technological needs occurs just before the branch to the heat exchanger on the supply and after opening the valve on the pipe, which returns te medium from the exchanger of the first stage, on the return. Depending on the conditions, especially the proportion of heating power demand for different purposes, the technological heat node supplies a separate differential pressure stabilization valve and heat meter, but it is possible to use common regulation and measurement devices for all needs in the node. The technological heat node can be connected directly or with the use of heat exchanger.

Multifunctional nodes

Source: Elektrotermex Sp. z o.o.

Definitions

Single-stage serial node – heating node with a heat exchanger for hot water production, the supply and return of which are connected to the heating network power line.

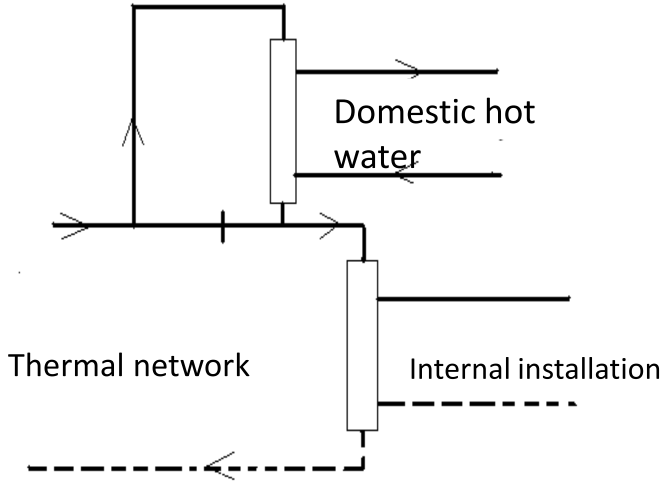
Single-stage paralel node – district heating unit with a heat exchanger for preparing domestic hot water, the supply of which is connected to the supply line, and return – to the return line of the heating network.

Two-stage serial node – district heating station with a heat exchanger for preparing domestic hot water, in which the 1st stage of the heat exchanger is connected in series to the return pipe, and the second stage – in series to the supply line from the heating network.

Two-stage serial – paralel node – district heating unit with a heat exchanger for preparing domestic hot water, in which the exchanger stage is connected in series to the return line of the heating network, and stage II in parallel, i.e. supply to the power supply line and return to the return network line.

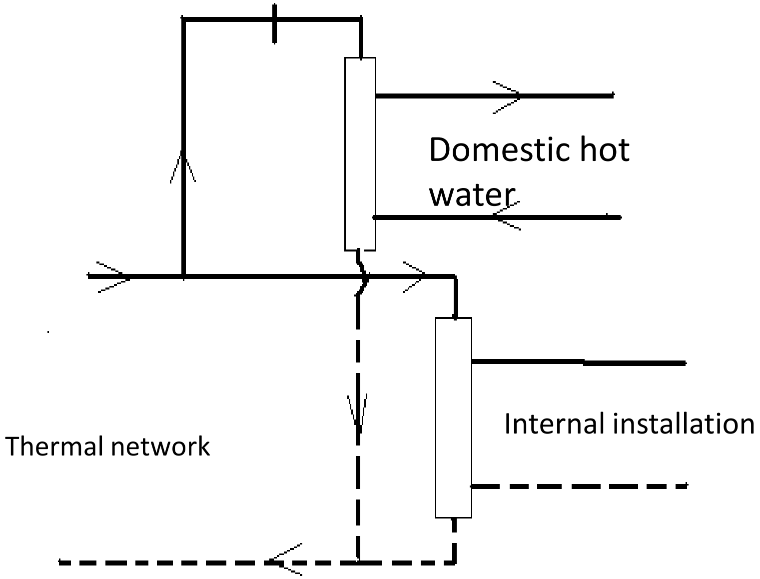
Single-stage serial node

The hot water is heated in one exchanger through which a part of the mass flow of the medium flows then is directed to the central heating system. Cooling of water after passing through the hot water exchanger should be taken into account when selecting a central heating exchanger. Area of heat exchangers c.o. and the network water stream will be higher than in case of water supply from the network with undefined parameters. Nodes with serial connections in the power supply lead to significant difficulties in ensuring proper flows of the heat carriers in individual circuits. The resultant hydraulic characteristics of the system depend on the degree of opening of the control valves, whereby the opening of the hot water control valve generally leads to an increase in the slope of the characteristic curve, i.e. in the opposite direction than that resulting from the optimal control algorithm.

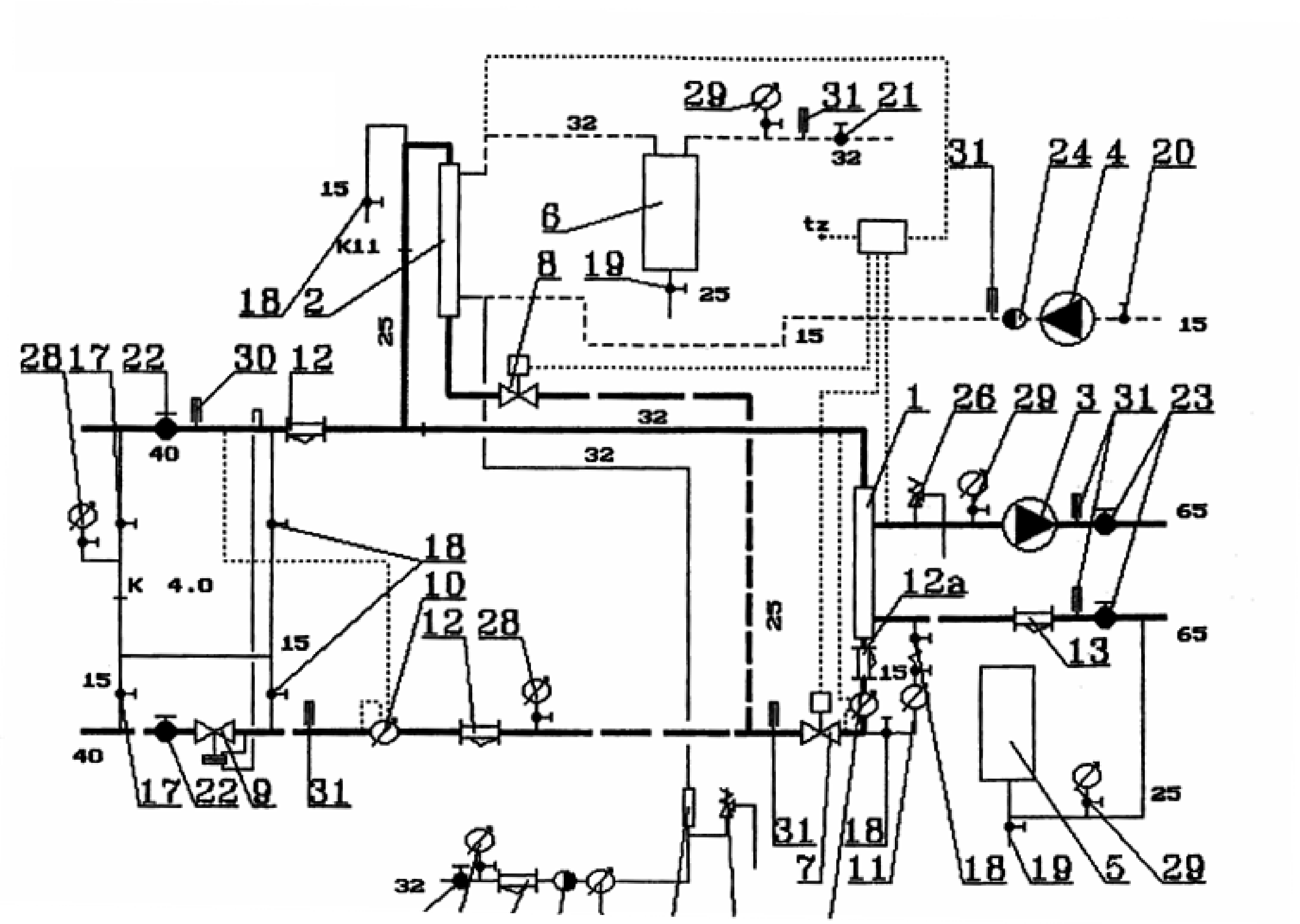


Single-stage paralel node

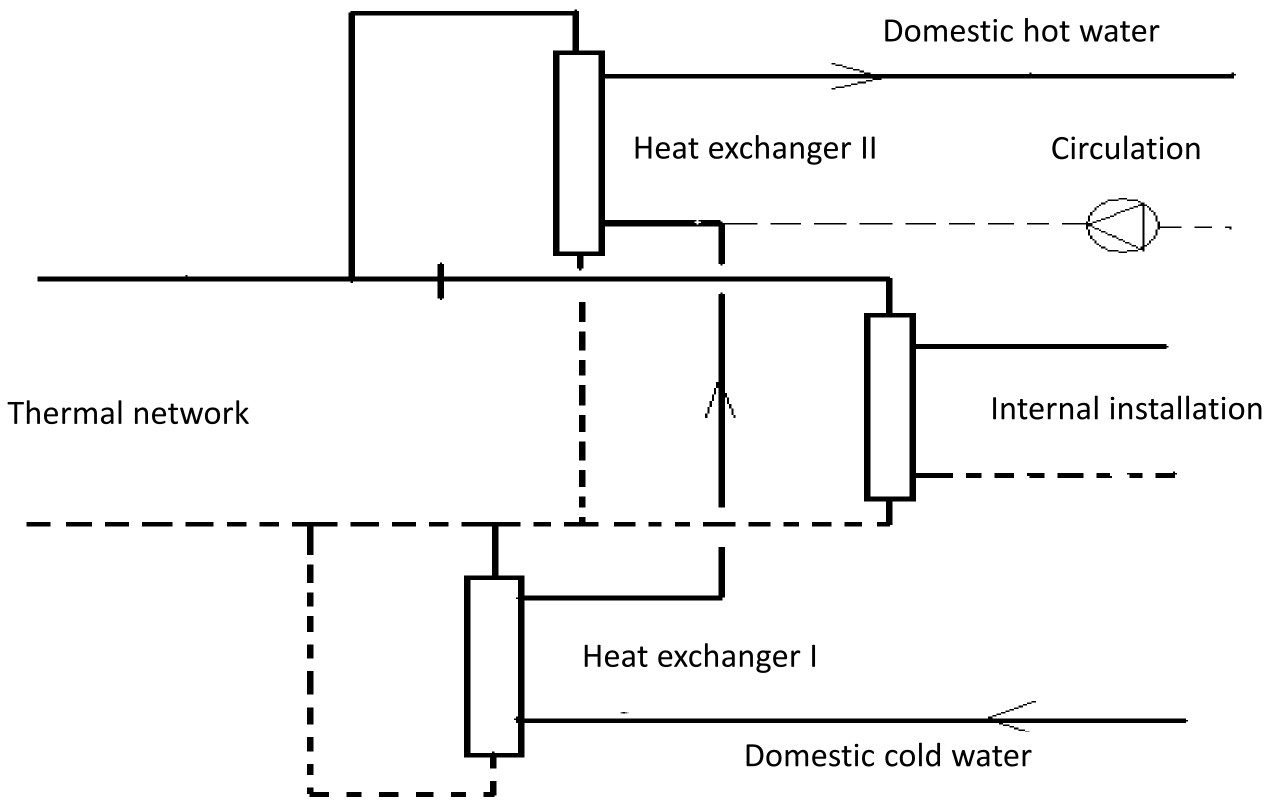
The hot water is heated in one exchanger, through which a part of the mass flow of the medium flowing into the node flows. The streams are separated so that each water is supplied with water at the same temperature. The figure shows how to connect parallel, single-stage central heating and central hot water. In each of the circuits should be certain necessary elements of equipment, such as fittings, control and measuring apparatus and automatic control devices. To ensure the required mass flows of the heating medium, it is necessary to equalize the pressure losses in individual circuits. This type of node, unlike serial, allows equalization of pressure losses for computational flows.



Single-stage paralel node



A two-stage serial-parallel node



A two-stage serial-parallel node

- The returning medium from the central heating system has a temperature of around 40–45°C on average, in least favorable conditions. **In order to use this heat**, the process of preparing the central hot water is separated into two stages (zones), the first of which is included after the central heating exchanger (1st stage of hot water preparation). The temperature of water returning from the DHW system, excluding the temperature of the outside air close to the design temperature, does not allow to completely cover the needs of DHW preparation.
- The duration of extremely low temperatures is not statistically too long, so in most times of the heating season it will be necessary to additionally heat the water leaving the first stage exchanger to the required temperature of 50–55°C.

A two-stage serial-parallel node

This heating is carried out in the exchanger connected in parallel to the central heating exchanger, similar to the one-stage parallel node. Water returning from the second stage exchanger can also be directed to the first stage exchanger.

In the case of older generation shell and tube heat exchangers, it was possible to direct the whole mass stream of network water to the first stage exchanger, in the case of new exchanger structures, the mass stream directed to the first stage depends on the type of equipment used and on the so-called priority of hot water. Part of the mass flow usually flows through the bypass of the first stage exchanger. It is the most common node type in current urban heating systems.

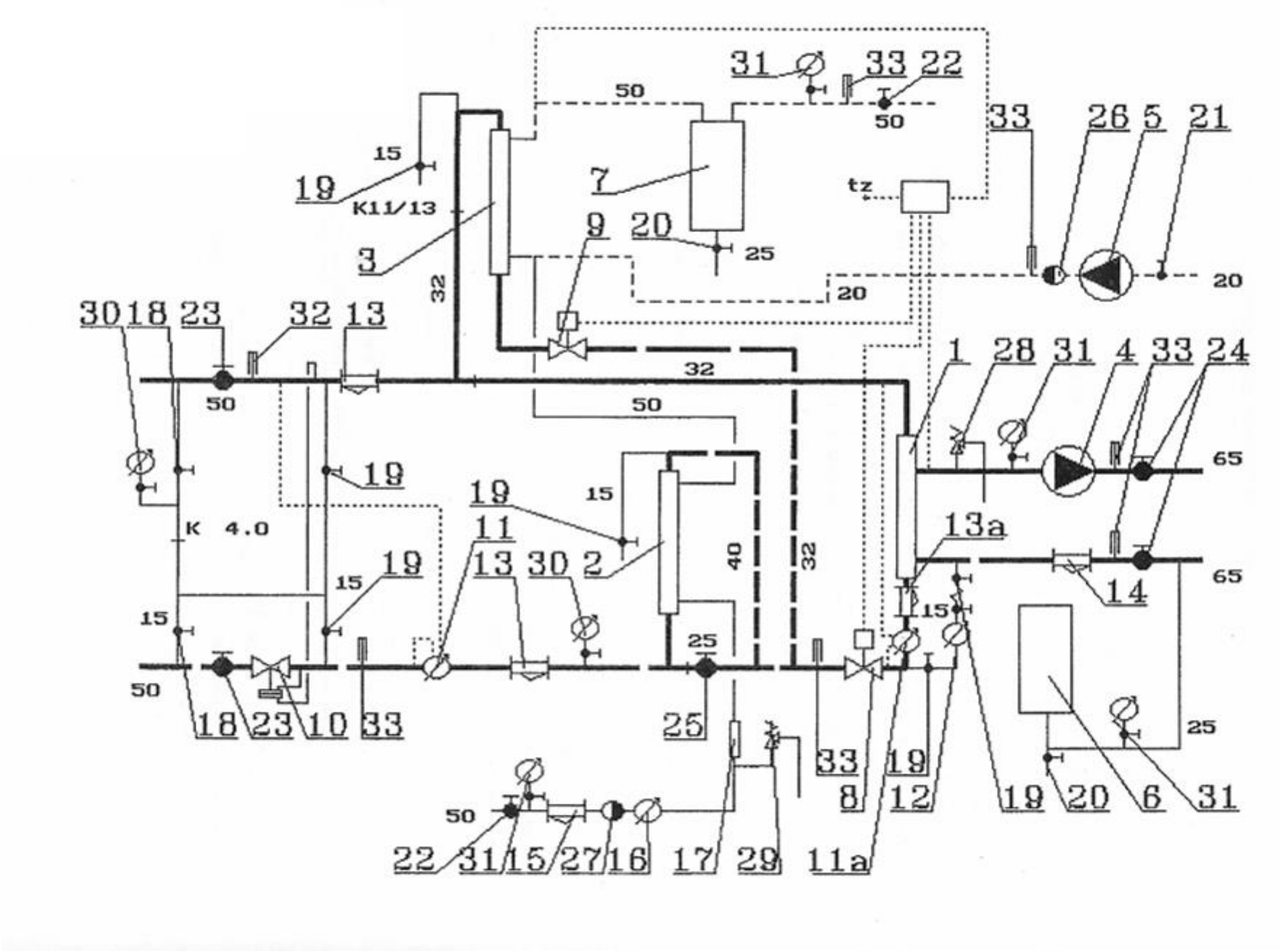
A two-stage serial-parallel node

The design model of two-stage systems for hot water, reproduced in textbooks and guidelines for node design, has survived to the present day. As can be seen from the upcoming figure, the critical design conditions for two-stage DHW heating occur at the beginning and end of the heating season, at the highest outdoor air temperature. In the absence of thermostatic valves in apartments (1980s), the temperature of the network water returning from the heating section was approx. 40°C, which allowed heating of utility water to approx. 30°C. The diagram of a two-stage hot water preparation is shown subsequently.

A two-stage serial-parallel node

The network water returning from the heating circuit, mixed with water coming back from the exchanger of the 2nd stage of hot water, supplies the 1st stage exchanger. Traditionally, the division of power of 1st and 2nd degree exchangers as 50/50% has been accepted. In modern heating systems in Poland and other countries of Central Europe, there has been a tendency for a dozen or so years to lower the nominal (computational) temperature of heating systems and indoor installations. In Poland, the parameters of the 120/60°C network prevail, in some cities are higher – 130/70°C, in some lower – 110/60°C, 105/60°C. The temperature of rooms heated at present is 20°C, commonly accepted parameters of the internal heating system are 70/50°C or lower. The heating season covers the outside air temperature range below 12÷15°C.

A two-stage serial-parallel node



The need for thermal centers

High parameters of heat transfer via district heating networks due to the possibility of transferring a large amount of heat through district heating networks with a limited diameter (1000 mm)

$$Q = \dot{m}_{WP} c_p \left(t_{zWP} - t_{pWP} \right)$$

Where: t_{zWP} = 135°C

t_{pWP} = 70°C

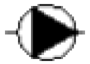
$$Q = \dot{m}_{NP} c_p \left(t_{zNP} - t_{pNP} \right)$$

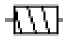
Where: t_{zWP} = 80°C

t_{pWP} = 60°C

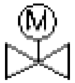
The use of lower parameters in buildings due to safety reasons – the diameter is not limited due to the lower values of power supplied.

Graphic symbols of thermal node elements

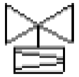

Pump

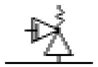

Filter


Cut-off valve

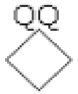


Control valve

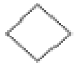

Differential pressure control valve

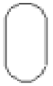

Safety valve

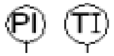

Check valve



Heat meter

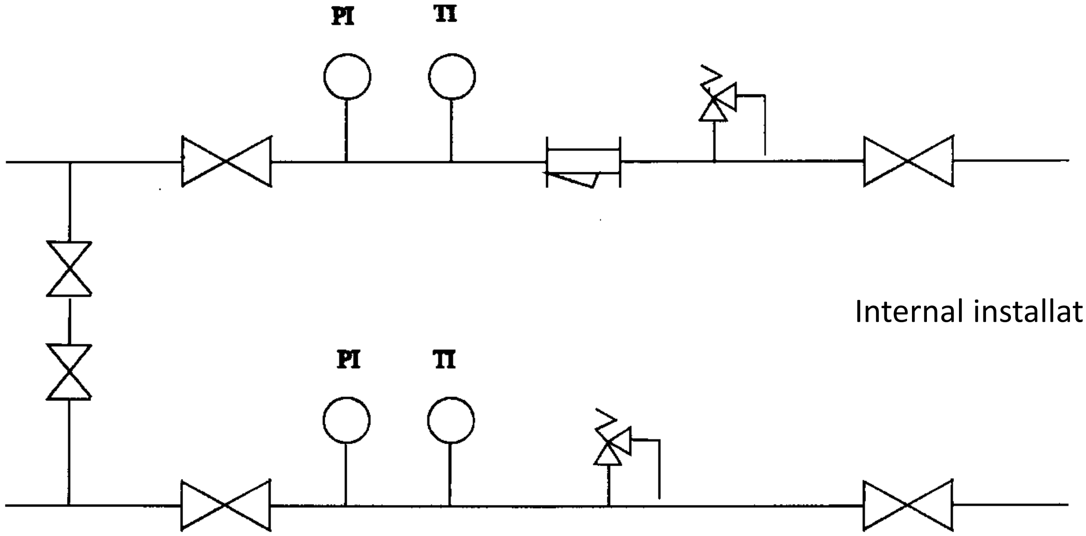

Flowmeter


Expansion vessel



Manometer, thermometer

Direct connection nodes without parameter transformation (without pressure differential valve)

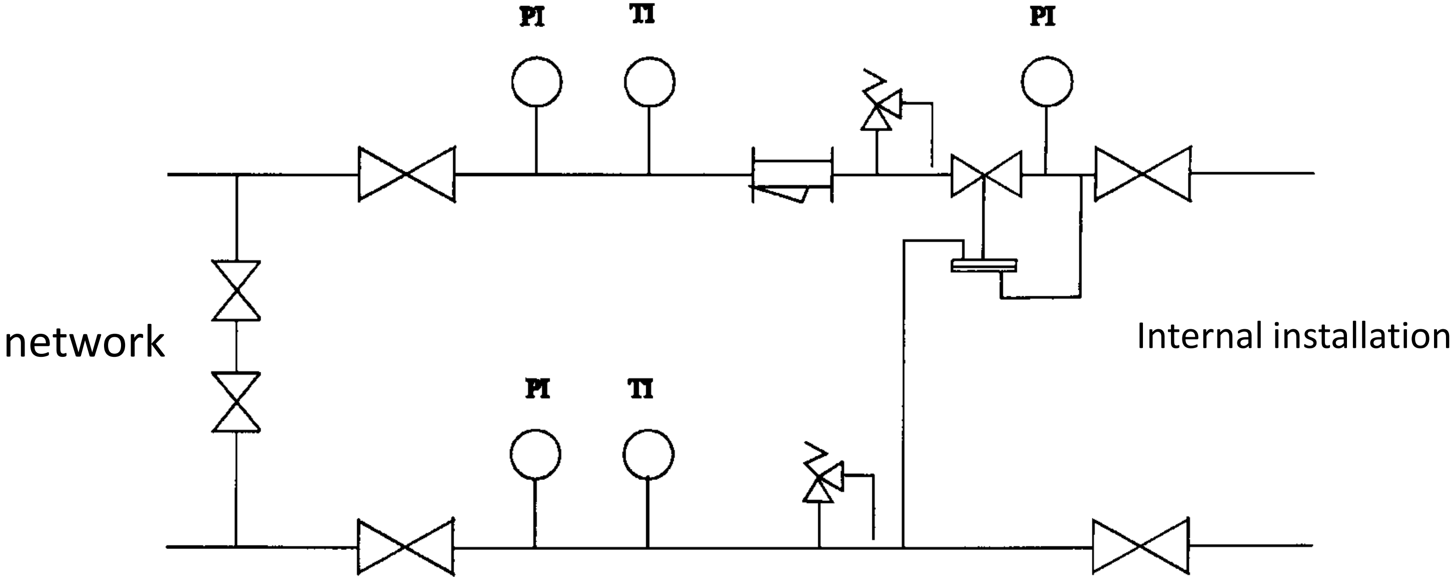


Internal installation

The direct connection thermal node is the simplest type of node. It can be used only in small scale heating systems, for example, hot water supplied from a local gas or oil boiler room.

Direct connection nodes are also used in industry, currently as low temperature (supply water temperature up to 100°C).

Direct connection nodes without parameter transformation (with differential pressure control valve)



Direct connection nodes

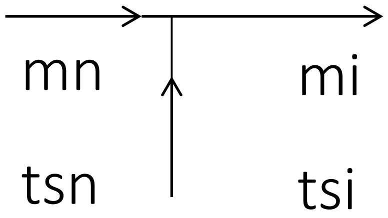
- the temperature of the supply medium does not change;
- **pressure can be reduced** by using throttling orifices or differential pressure regulators – they are not devices protecting against pressure increase in the system;
- installation connected to the network via a direct connection node **should be resistant** to the pressure prevailing in the network;
- the throttling orifice selected for the so-called "calculation conditions" will have a different resistance for smaller than calculated mass streams, hence **the possibility of exceeding the maximum pressure** in the installation may occur, if it is lower than the network operating pressure;
- the task of the differential pressure control valve, is to maintain the differential pressure in the supply and return line at a constant level. This is generally a proportional device with a specified proportional band;
- characteristics of these types of devices in the extreme positions of maximum opening and maximum closing usually deviate from the proportional theoretical characteristics and the valve can "pass" more pressure from the network to the installation;

Direct connection nodes

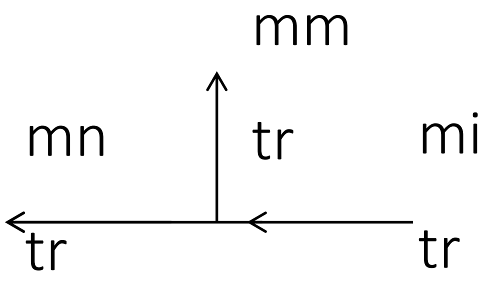
- for this reason, a safety valve is an indispensable element of the thermal connection of the direct connection. The location of the valves is specified in the standard (qualified for mandatory use) PN-B-02416: 1991 and in accordance with it, two safety valves should be used, one in the supply line and the other in the return pipe;
- each node supplied from the heating network, the section of which connects after being shut down from service, could freeze at low outside temperatures, should be provided with a so-called circulating bypass, usually equipped with two shut-off valves and, sometimes, a pressure gauge between the valves;
- an indispensable element at the entrance to the node is a filter or device with a similar effect. Some heat engineering companies require additional filters in the return water line to the district heating network;
- in direct connection nodes without transformation of parameters, the design temperatures of networks and installations are identical, e.g. 150/70°C or 120/60°C.

Direct connection nodes without parameter transformation

SUPPLY
network – installation



RETURN
network – installation



$$mi = mn + mm$$

$$mi * tsi = mn * tsn + mm * tr$$

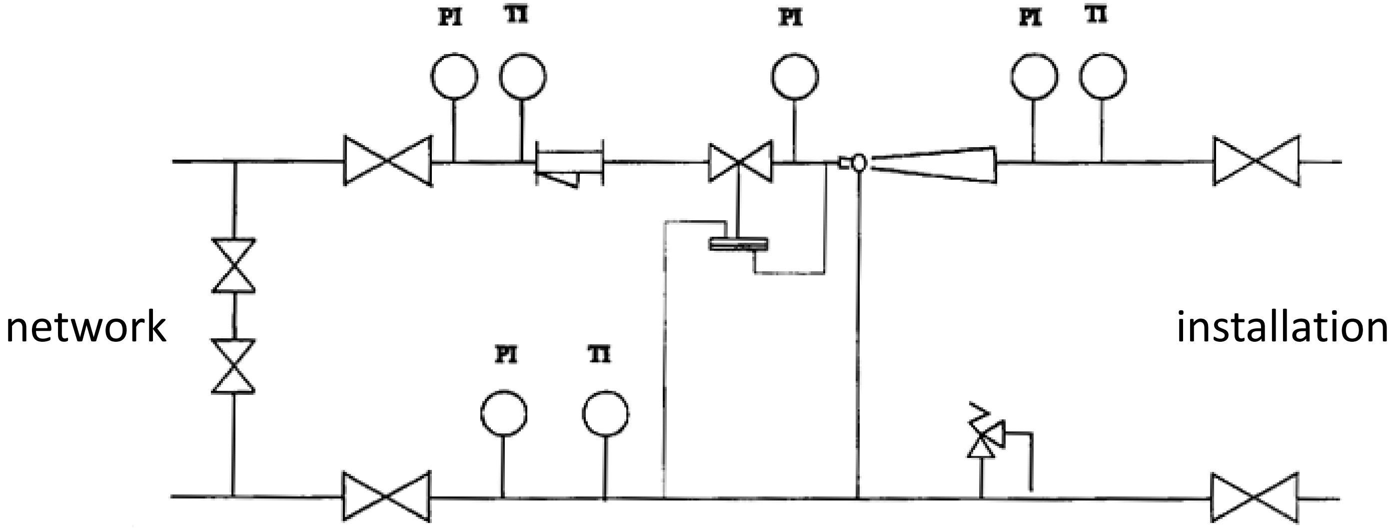
$$\text{Mixing ratio } a = \frac{tsn - tsi}{tsi - tr}$$

N – network, s – supply, m – mixing, r – return, i – installation

Sample values of the mixing ratio

Network parameters °C	Installation parameters °C	α
150/70	95/70	2.2
150/70	90/70	3.0
130/70	95/70	1.4
130/70	90/70	2.0
120/60	80/60	2.0

Hydroelevator’s nodes



Pressure increase in the internal installation caused by:

1. Increase in pressure in the return of the heating network.
2. Stoppage the flow in the heating network.
3. Variable hydraulic characteristics of the indoor installation.
4. Errors in handling the node.

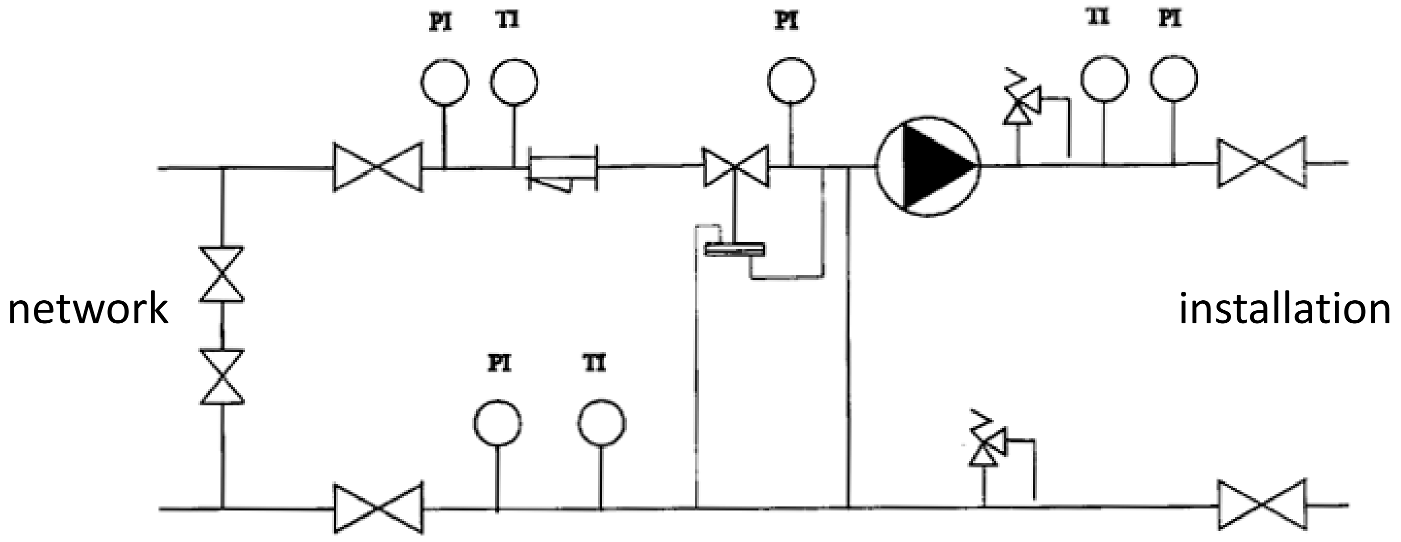
Pump mixing nodes

The pump can be placed

- in the supply pipe,
- in the return pipe,
- in the mixing line.

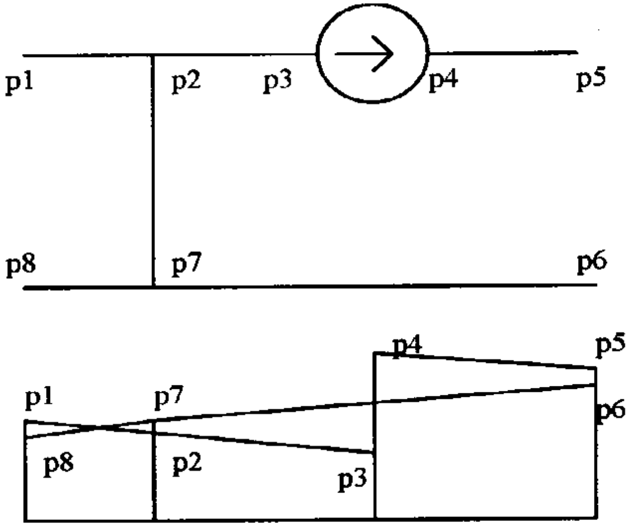
The choice of one of the above schemes results from the analysis of the pressure system in the network and the necessary pressure levels in the installation: static (fill) and maximum (admissible) pressure. In the **first and second** cases, the flow parameters of the pump should correspond to the volume flow of water in the installation, in the **third** – volume flow in the mixing line. The lifting height of the pump should ensure that it can **overcome the pressure difference** between the points of its activation **along with the flow resistance** in the relevant sections of the pipelines. These quantities are determined based on the assumed design parameters of the indoor installation. It is also necessary to take into account the resistance of flow through the automatic control elements.

Diagram of a pump mixing node with a pump in the supply pipe



In accordance with the requirements of PN-B-02416: 1991, two safety valves should be installed in the pumping mixing nodes: in the supply and return pipes. The schematic diagrams of the pump mixing station (without automatic temperature control elements) is shown in the figure.

Diagram of a pump mixing node with a pump in the supply pipe. Pressure graph

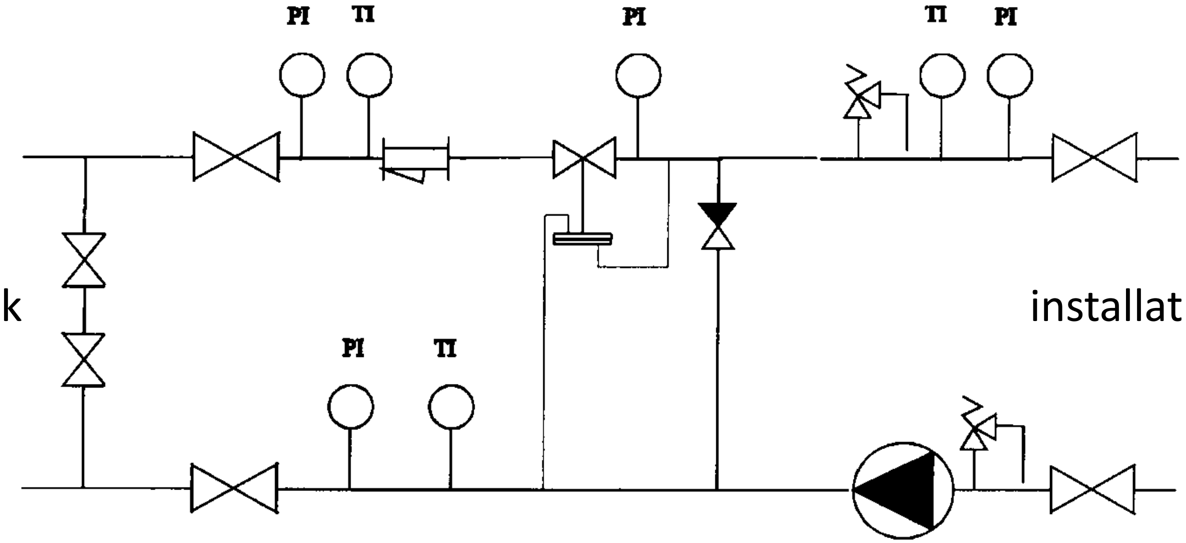


To ensure proper flow direction in the mixing line it is necessary that the pressure in the return line (p7) is higher than the pressure in the supply line (p2).

The condition to protect against this phenomenon is to have adequately high available pressure, so this configuration **should not be used in the final parts** of district heating systems with insufficient available pressure. A sufficient excess pressure should be provided in the supply or return line to allow the pressure control valve or differential pressure valve to be fitted.

In order to ensure proper operation of the pump mixing node, the available pressure difference at the point where the node is connected to the network should be negative (return line pressure less than in the supply line) or close to 0.

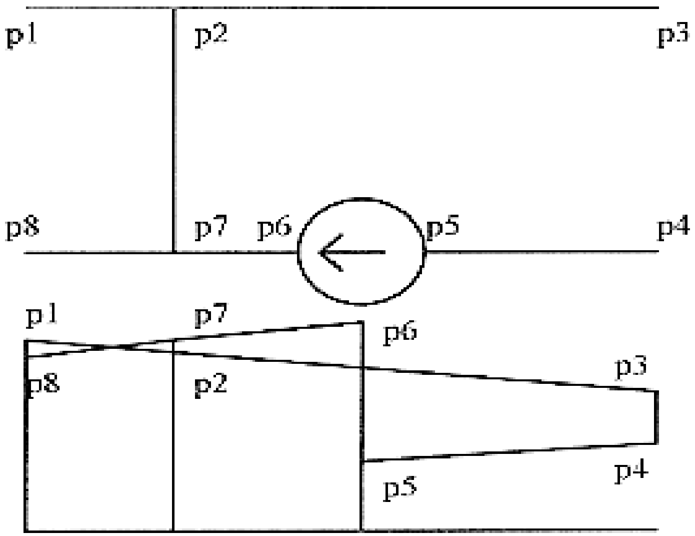
Diagram of a pump mixing node with a pump in the return pipe



network

installation

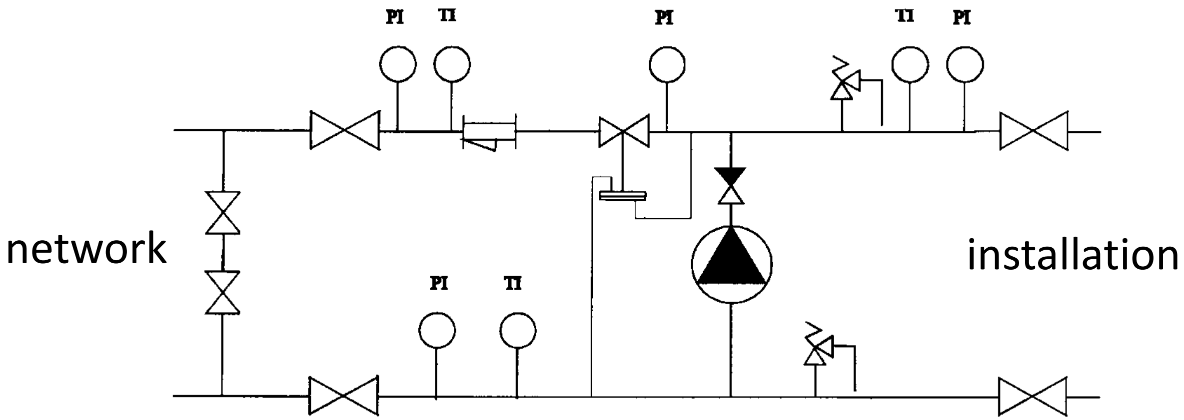
Diagram of a pump mixing node with a pump in the return pipe. Pressure graph



- The effect of reversing the piezometric plot in the node with the pump in the return pipe is analogous to that in the node with the pump in the supply line. The level of pressure in the installation relative to the network is different. A differential pressure stabilization valve, depending on the relative pressure system, can be placed in the supply or return line.

This system is rarely used in heating.

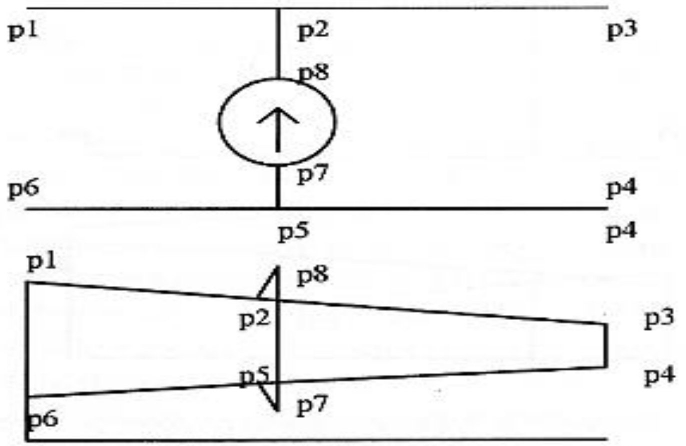
Diagram of a pump mixing node with a pump in the mixing pipe



A positive value of available pressure difference at the point of substation start-up within the network can only occur in a system with the pump in the mixing line. Therefore, this system is functionally predestined for cooperation with the district heating network.

It can only be used in small heating systems supplied from gas or oil boiler rooms. In centralized, medium and large heating systems, direct connection nodes are not used due to obvious inconveniences: difficulty in shaping the pressure in the network with variable load and the possibility of impact of the internal installation on the heating network (losses and water pollution).

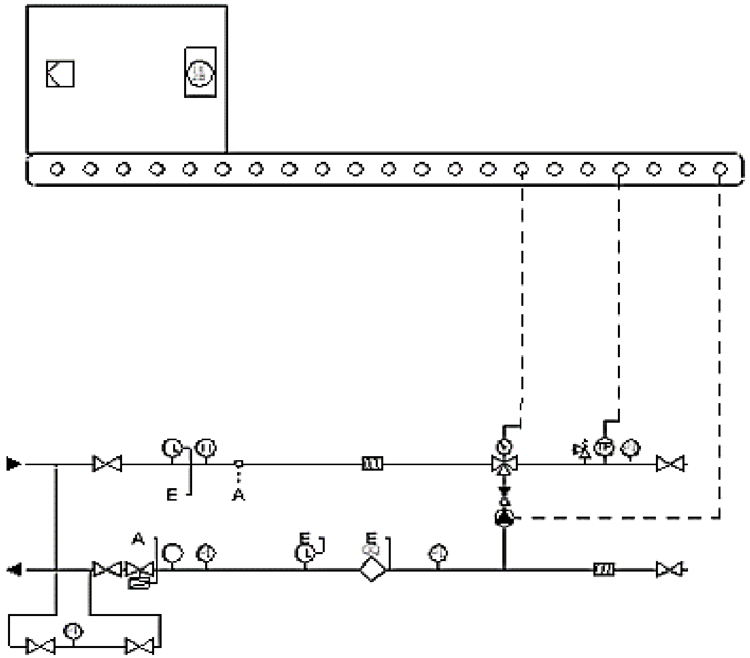
Diagram of a pump mixing node with a pump in the mixing pipe. Pressure graph



There is no "reversal" of the piezometric graph in the mixing pump with the pump in the mixing line. In the pump mixing nodes a certain pressure system is assumed when the pump is in motion. When the power supply is switched off, the system pressure changes and is positive (it can be equal to 0), water may flow into the indoor installation at a temperature equal to the supply temperature from the network. In addition, placing the pump in the return or mixing line exposes it to the reverse flow of the medium during the loss of electricity. The non-return valve in the mixing line.

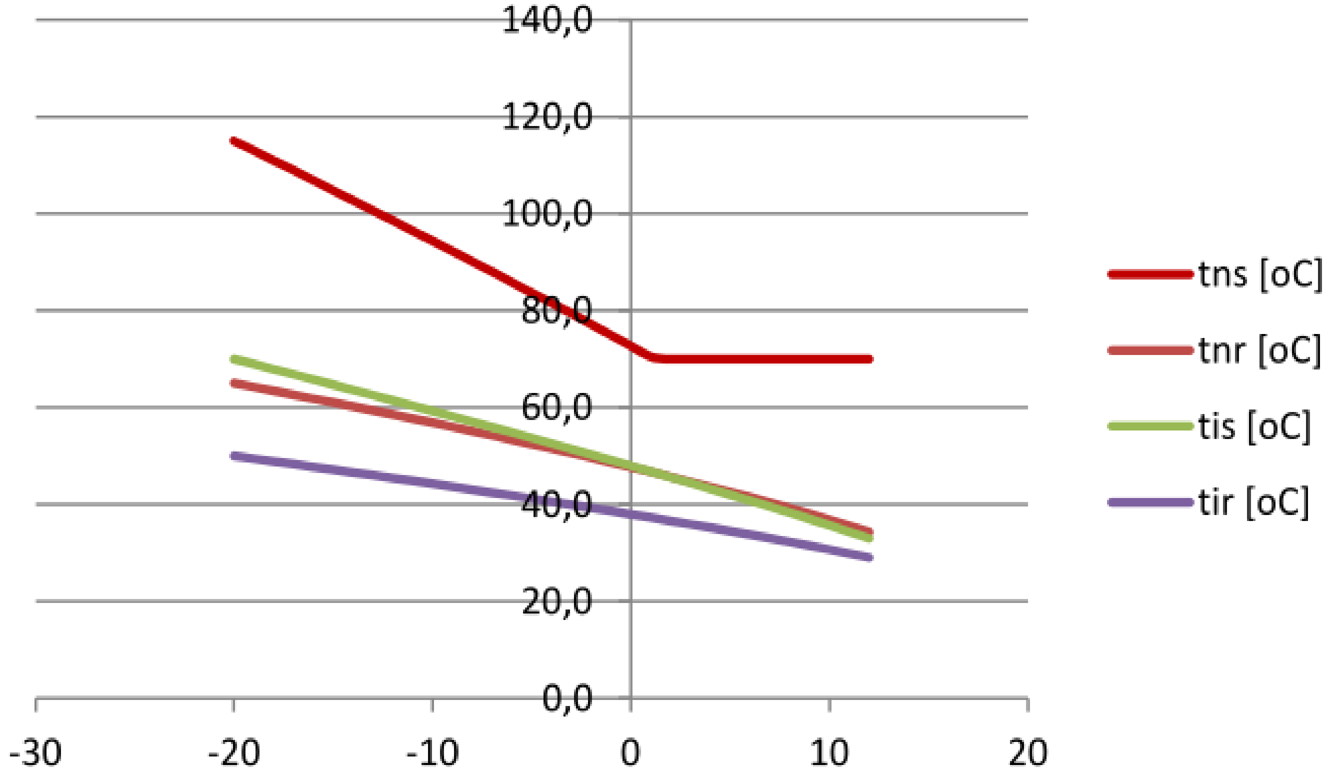
In the system with the pumps in the supply line, such a valve is unnecessary.

Simplified diagram of a pump mixing node with a pump in the mixing pipe

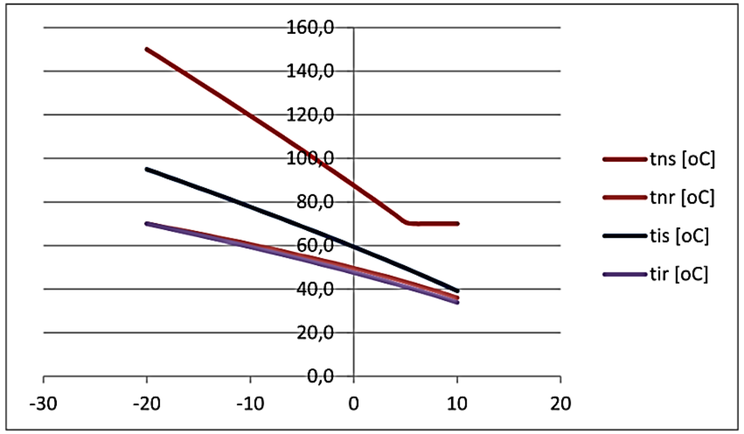


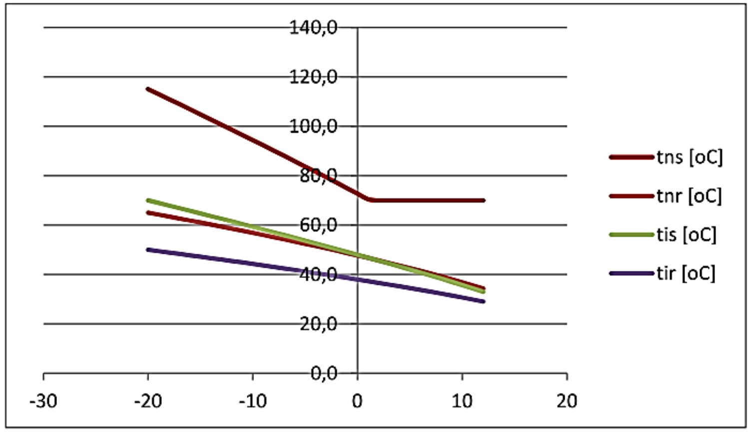
The heat meter and differential pressure control valve (and flow restriction) can be placed in the return or supply line, depending on the requirements of the Heating Company. This type of node can only be used if the maximum pressure in the heating network is not greater than the acceptable pressure in the indoor installation. The safety valve only works in the event of an emergency.

A typical modern regulatory chart for networks and installations in Poland (3rd climate zone)



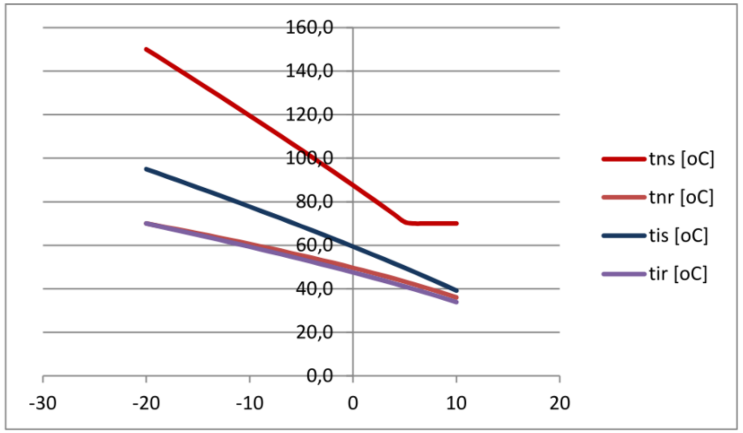
Comparison of regulatory and installation charts in Poland

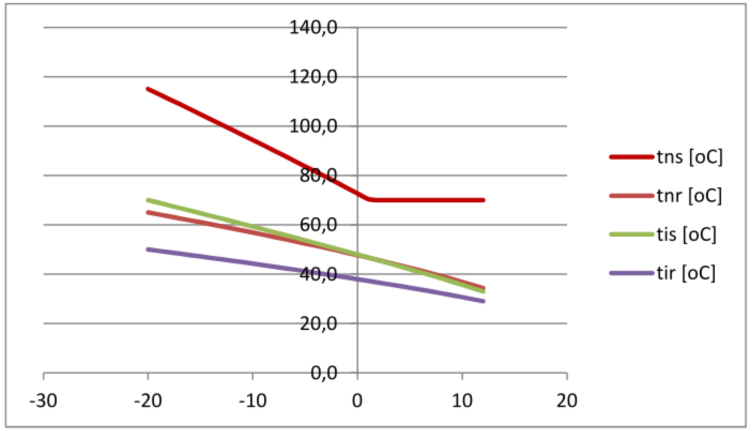




A significant expansion of the area beyond (to the right) point of collapse of the regulatory chart (about 1^{o}C), especially in relation to the duration of this period, can be seen in relation to the previous chart. In about 60÷70% of the total heating season, the supply water holds a constant temperature, thus in the heat node there is a quantitative adjustment. The occurrence of this phenomenon requires adaptation of pumping units in heat sources for cooperation with a heating system with quantitative regulation. As can be seen from the diagram, the return water temperature from the primary heating circuit is approx. 32^{o}C. This is the temperature determined assuming no thermostatic valves at the radiators in the rooms. Even in the absence of thermostatic valves, the actual return temperature to the network is lower, as the return temperature of the network water approaches the temperature of the water returning from the indoor installation.

Comparison of regulatory and installation charts in Poland





Thus, the minimum temperature of network water returning from the heating section is approx. 27°C. The use of water at this temperature for heating domestic water is problematic. The equipment of the internal installation with thermostatic valves at the radiators **introduces a quantity element** for regulation in the secondary heating circuit. As a result of thermostatic valves, for example, in the presence of internal and external heat gains, the **mass flow and the return temperature of the water flowing through the radiator are reduced**. The period with the highest outside air temperature is characterized by quite high heat gains, so at the critical point of the design of the two-stage hot water system, the temperature of water returning from the primary heating section may be even lower than that resulting from the control chart.

Two-stage, single-stage?

The temperature of water returning from the installation at the highest ambient air temperature is 20^{o}C. The return temperature of the supply water will be close to the temperature of the installation water. In the heating installation there may be conditions **practically preventing the operation of the 1st stage exchanger**. Water returning from the heating section will negatively affect the conditions for the exchanger 1 stage by reducing the temperature of the water returning from the exchanger 2 stage. Lowering the temperature of water returning from the heating circuit is accompanied by a reduction in the flow rate, which significantly reduces the possible thermal potential of the return water from the heating circuit. There is no justification for using two-stage hot water preparation nodes in modern heating systems, although such solutions appear in the guidelines for designing heat distribution centers, not only in Poland. The single-stage hot water preparation node, designed in accordance with modern design standards, is characterized by a smaller mass stream of network water and a lower temperature of water returning to the network than a two-stage node designed according to the previously used principles.

Inlet of high parameters – filter desludger

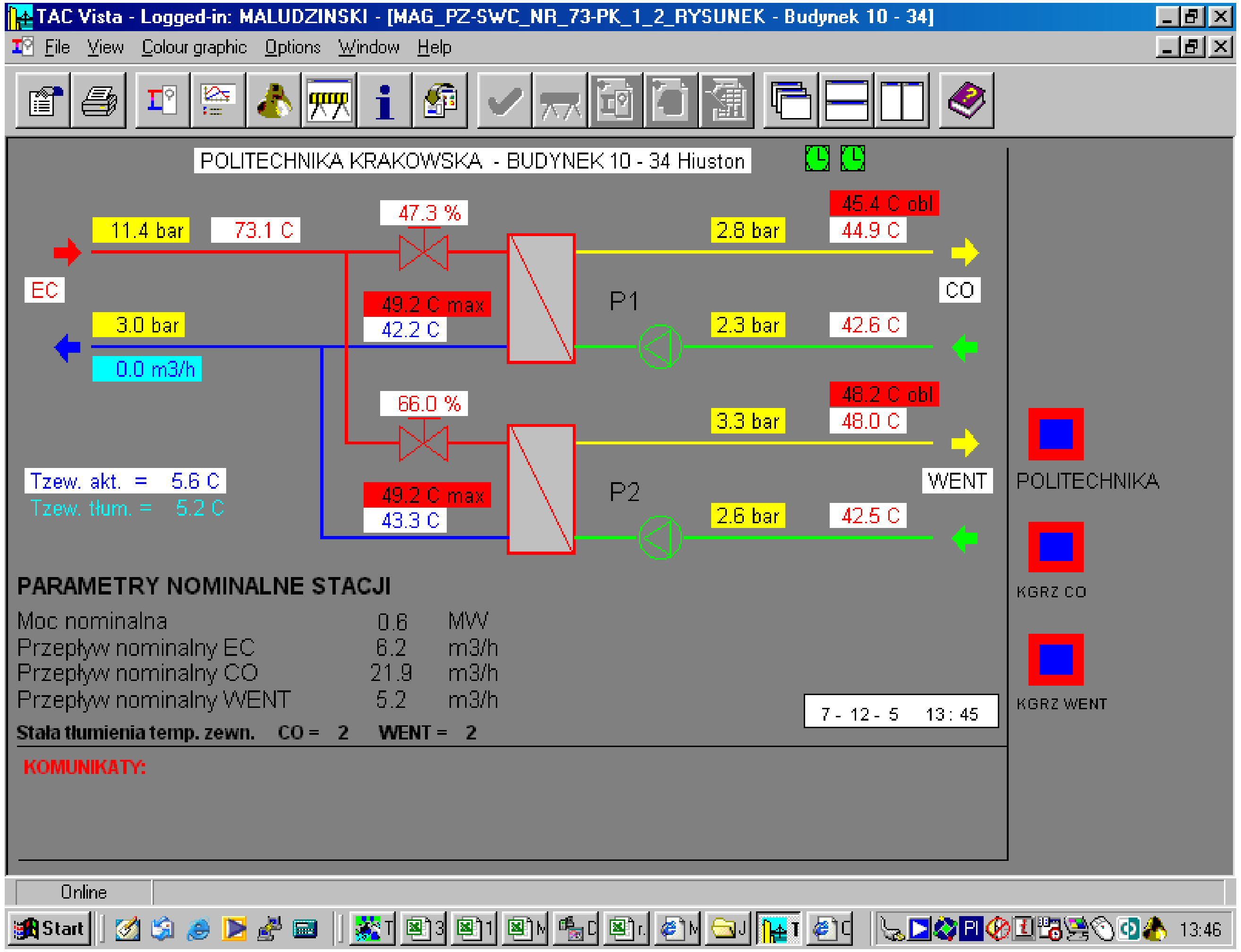
Heat exchangers station

Heat exchangers – supply and return collectors

Pumps supplying individual heating circuits

Diaphragm expansion vessels with a pressure relief device (or with a pump-bleed device) – pressure automatic devices stabilizing the water pressure in the installation

Diagram of a substation in Houston PK



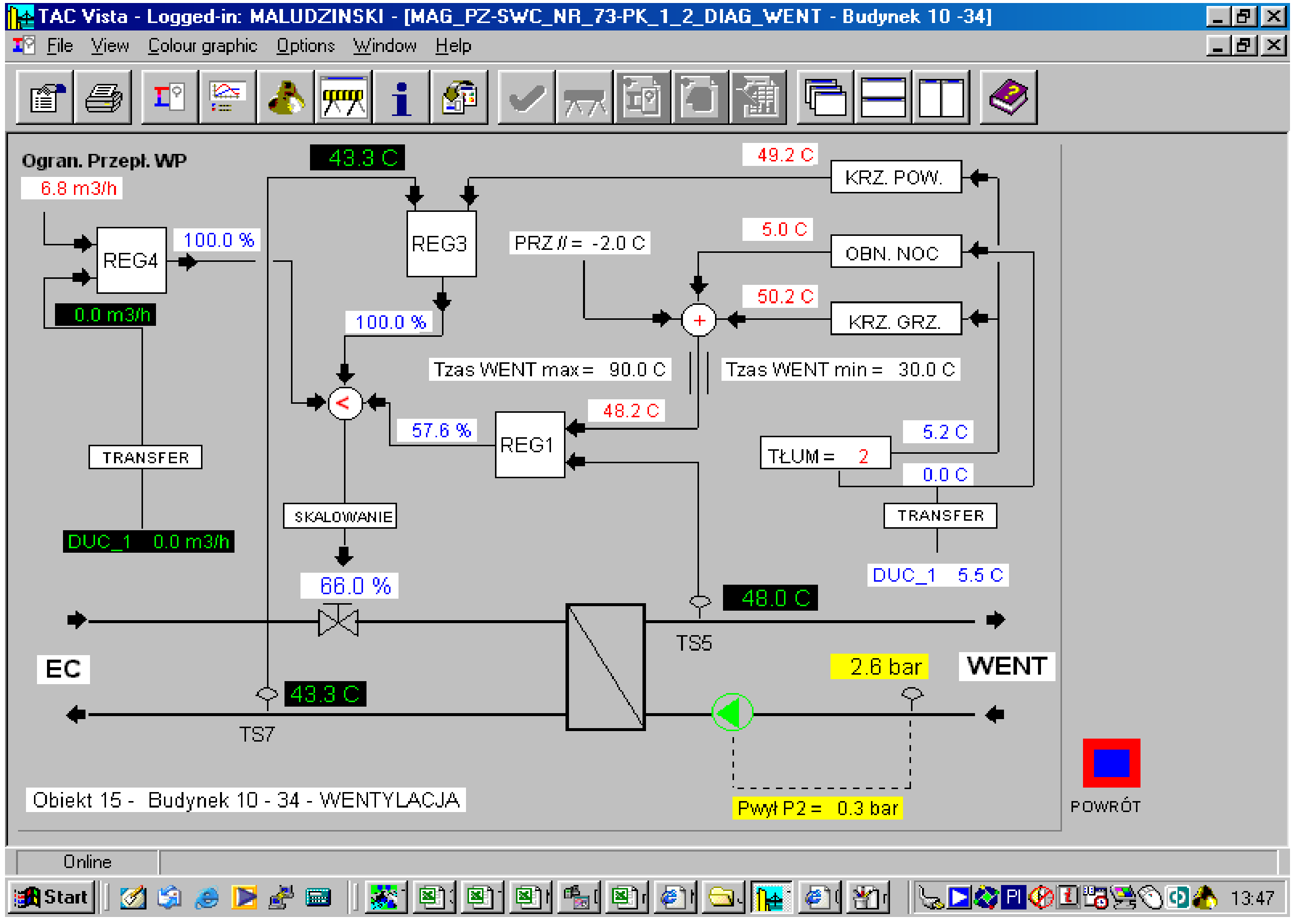
PARAMETRY NOMINALNE STACJI

Moc nominalna	0.6	MW
Przepływ nominalny EC	6.2	m3/h
Przepływ nominalny CO	21.9	m3/h
Przepływ nominalny WENT	5.2	m3/h

Stała tlumienia temp. zewn. CO = 2 WENT = 2

KOMUNIKATY:

Schematic of the regulator in the thermal substation in Houston PK



Ogran. Przepl. WP 6.8 m3/h

100.0 %

0.0 m3/h

DUC_1 0.0 m3/h

43.3 C

100.0 %

57.6 %

66.0 %

49.2 C

PRZ // = -2.0 C

5.0 C

50.2 C

Tzas WENT max = 90.0 C

Tzas WENT min = 30.0 C

48.2 C

5.2 C

TŁUM = 2

0.0 C

DUC_1 5.5 C

48.0 C

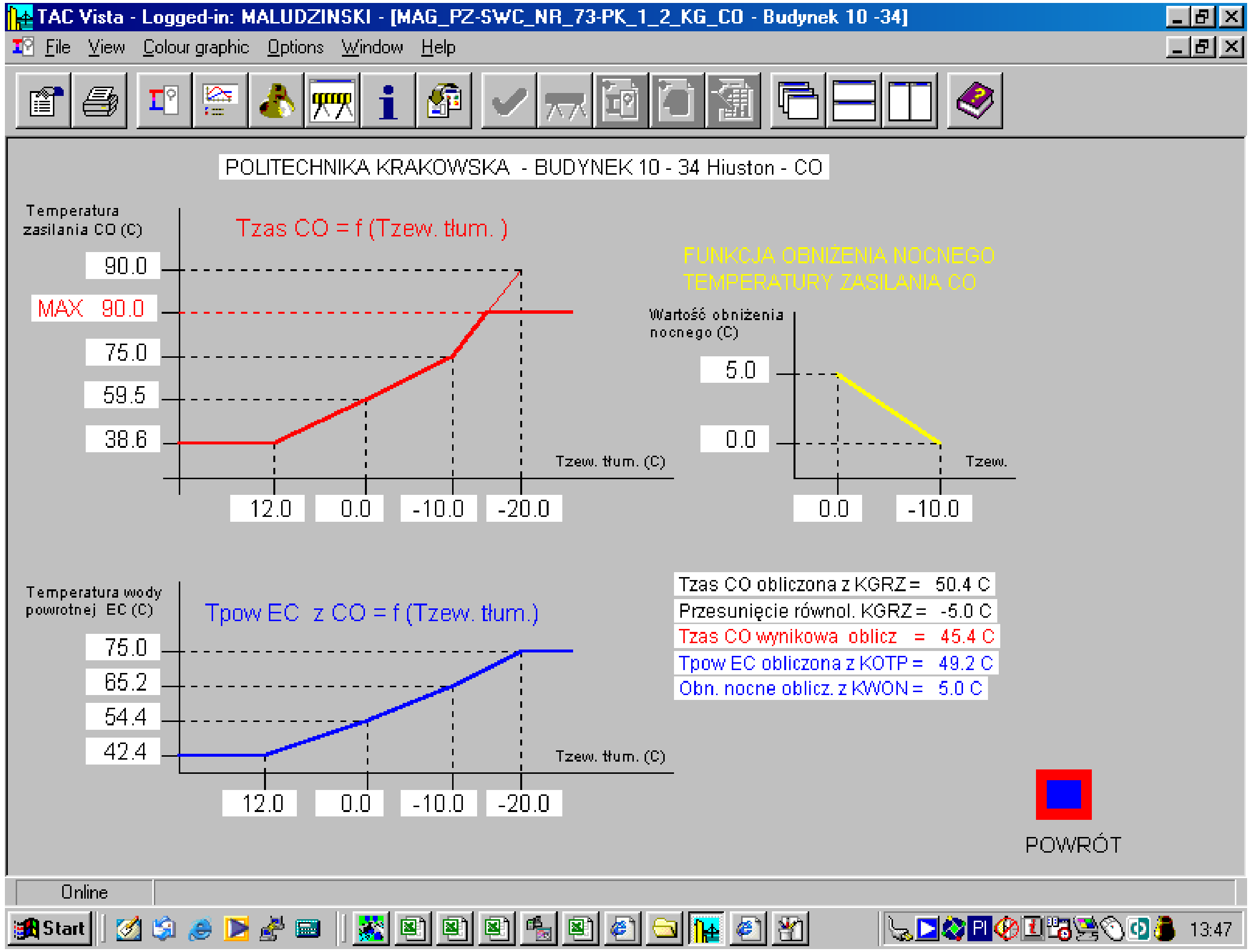
2.6 bar

43.3 C

Pwył P2 = 0.3 bar

Obiekt 15 - Budynek 10 - 34 - WENTYLACJA

The heating curves of the regulator in the heating node at Houston PK



POLITECHNIKA KRAKOWSKA - BUDYNEK 10 - 34 Hiuston - CO

Tzas CO obliczona z KGRZ = 50.4 C
Przesunięcie równol. KGRZ = -5.0 C
Tzas CO wynikowa oblicz = 45.4 C
Tpow EC obliczona z KOTP = 49.2 C
Obn. nocne oblicz. z KWON = 5.0 C

References

Górecki J., *Sieci cieplne*, Skrypt Politechniki Wrocławskiej, Wrocław 1997.

Linke G., *Power Storage in Smart Natural Gas Grids: Fiction or fact?*, International Gas Union Research Conference, Seul 2011.

https://poradnikprojektanta.pl/projekt-instalacji-gazowej-w-25-krokach/

http://www.poradnikprojektanta.com

http://www.pracowniasanitarna.pl

https://poradnikprojektanta.pl/projekt-instalacji-gazowej-w-25-krokach/

Cracow University
of Technology

eISBN 978-83-66531-25-3