Production

The production takes place in a plant in which the energy of the fuel in question is converted into heat through combustion and then transferred to the water of the distribution network.

1. Environmental requirements

The environmental requirements on fuel are made more and more stringent. The contents of environmentally hazardous substances in coal and oil have diminished considerably during the past ten years. There are also requirements on the volume of dust discharges of the ashes after good combustion. In cases where the requirements made on the fuel cannot be fulfilled, a penalty tax is imposed, and/or a plant reducing the environmental influence to the established level is requested.

The pollutants, set free by the combustion, are spread with the winds covering very large areas. It is not sufficient only to limit the discharges locally, but the same requirements are necessary all over Europe. Certain values have been established and a tightening-up of the requirements will be carried out, as people in many countries find the values too high.

Sulphur causes acidification of the ground which kills both plants and animals. Nitrogen also causes acidification and have negative effects on the ozone layer. Both these substances travel great distances and measures must be taken right at the source.

Opposite, see tabel, are allowed discharges according to IEA Coal Research air pollutant emission standards for coal-fired plants database, 1991.

<table>
<thead>
<tr>
<th>Particles mg/m³</th>
<th>SO₂ mg/m³</th>
<th>NOₓ mg/m³</th>
</tr>
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<tbody>
<tr>
<td>EC 50 – 100</td>
<td>400 – 2.000</td>
<td>650 – 1.300</td>
</tr>
<tr>
<td>Minimum</td>
<td>160 – 270</td>
<td>80 – 540</td>
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The values relate to new plants. The first value is for big plants and the second value for small ones.
Hydrocarbons derived from motor-driven vehicles and industrial processes contribute to the fact that ozone is formed close to the ground and the fact that the ozone layer is demolished.

Greenhouse gases, carbon dioxide, nitrous oxide and methane are all contributing to the so-called greenhouse effect. Carbon dioxide is formed by different sorts of combustion, in central heating plants, in car engines etc.

Heavy alloys, which influence the germ plasm, are stored all the time, and gradually they end up at the top of the food chain, i.e. in predators and in human beings.

2. Fuel

Oil and coal are the fuels most frequently used. Natural gas is more and more used as well as biofuel (renewable energy such as forest waste and straw).

Coal is refined through washing so that the content of pollutants and ashes will be less than before. The sulphur content is under 0.8%. By spraying with surface chemicals or with water only, the dust amount from transport and handling has been reduced. Pulverized coal is a processing operation that increases the efficiency of handling and combustion. Efficient purification of the exhaust gases is required, bearing in mind solid particles, sulphur and nitrogen gas.

Because of the large volumes in connection with district heating, the transport must be carried out by ship, unless of coal mine is located near the district heating plant.

Oil for large district heating systems, so called heavy oil, contains a maximum of 0.8% sulphur and can be very efficiently burnt with present techniques, but to reduce the discharges to the accepted level, purification of the exhaust gases is required.

The oil is transported by ship and lorry or by train.

Gas can be purified from possible pollutants before combustion, but nitrogen remains even after the combustion.

When dealing with large quantities in liquid form, transport is undertaken by special tankers or through gas pipe-lines.

Biofuel is mostly used in minor plants, up to 10,000 apartments, 700,000 m². Biofuel is not considered to have negative effects on the environment, as the carbon dioxide, released by the combustion, is used when the corresponding amount of biofuel is building up.
The resistant ashes are to be brought back to the specific site from where the fuel has been collected. Purification of the gas fumes is required.

When using biofuel, it is essential from an economic as well as environmental point of view, that the combustion plant is located close to the area from where the fuel is collected. The biofuel is transported by lorry. Waste heat or surplus heat from an industrial process, e.g. cooling water with a high temperature can be used in the district heating network. Classic examples of such processes are the manufacturing of glass and the refining of oil.

3. Exhaust emission control

In earlier years chimneys were built higher when the dust quantities were a nuisance, but experience has shown that this method only shifted the problem further away from the chimney. Nowadays the exhaust gases are, as a rule, mostly purified as for as sulphur, nitrogen oxide and particulates.

Particles are separated with the help of cyclones, mechanical filters or electro-filters.

Sulphur is separated by adding lime, with plaster as the end product. There are several methods and they are developing all the time. The separation degree is as high as 95%.

Nitrogen oxide is separated by injecting ammonia. A separation level of 90% can be reached.

Principle for purifying the exhaust gases.  
Fig. 2:5
4. Water quality

The water quality is of great importance and affects the whole system’s requirements for maintenance and durability.

When installing boilers, complete with equipment, welding and laying of pre-insulated pipes, and also when installing heat exchangers in the substation, a lot of strange impurities end up in the district heating system. They can be anything from welding sparks and iron oxides to sand and gravel. If these impurities remain in the system during operation, they will damage valves, pumps and other components, and also some block parts and form layers reducing the heat transfer. To prevent this, all parts of the system must be carefully flushed before filling it with water, and strainers installed upstreams of sensitive equipment, such as regulating valves and flow meters.

Leakage threatens the operation safety, and that is why all welded joints are X-ray tested.

The temperature, and pressures in the systems are so high that pipes and components are classified as pressure vessels. After the pressure test of the plant has been made, it still remains to protect it against corrosion.

Corrosion may occur on the inside or on the outside. External corrosion can be avoided by securing a dry environment. To prevent internal corrosion, a water quality that does not cause corrosion is required.

Oxygen causes corrosion and ordinary water contains oxygen. Water, with a temperature of 10°C, may contain 11,25 mg oxygen per kg at a pressure of 0,1 Mpa (1 bar).

Once the water has been heated to 100°C, it cannot contain any oxygen. Each mg oxygen supplied to a district heating system uses about three times as much iron. Consequently, the water is pretreated by, for instance, heating it to about 100°C before using it in the system.

Water contains other "pollutants" which may cause problems in heating systems, for example lime, sludge, chloride and sulphate.

When calcareous water is heated in the boiler or in the heat exchanger, calcium carbonate (CaCO₃) or limestone is formed on the heat transferring surfaces. A layer of 1 mm thickness increases the heat consumption by 10%, a layer of 2 mm thickness increases the heat consumption by 18% and a layer of 10 mm increases the heat consumption by 50%. The problem with limestone is solved by using a wet filter, which exchanges the lime and the magnesium salts in the water for sodium salt.
There may be sludge or mud in the water used for re-filling, but mud can also be formed in a chemical reaction between the water and the components being part of the system. The result could be calcium carbonate, iron and copper oxides, copper sulphides (providing the water pipes are made of copper) and calcium phosphate. The sludge sinks and ends up in places where the water speed is low, for example at the bottom of radiators. Pitting (corrosion), which may rapidly lead to leakage, especially in radiators of sheet metal, is easily formed under these situations.

A mechanical filter is used to remove mud from the water.

Large contents of chloride and sulphate in the water result in high conductivity, which may lead to corrosion. These salts are removed through reverse osmosis.

The water that is used for re-filling, after the first filling, is treated in the same way before re-filling. There is no leakage in modern pre-insulated piping systems. The re-filling of water is to compensate for the water that has been let out as a result of coupling up of new parts of pre-insulated pipes or sub-stations. Various chemicals are added to the systems in order to reduce the risk of corrosion, and checks are made regularly in order to ensure the quality of the water.
5. Flow and return temperatures

The flow temperatures in a district heating system vary a great deal, from under 100 °C up to 160-170 °C. The flow temperatures have one thing in common, a large temperature drop, and that also applies to pure heat production. A large temperature drop leads to a reduced flow which means smaller pipe dimensions and smaller pumps. The operating costs are lower for the smaller pumps, and the losses from the smaller pipes are also less.

Heating plants are often built with the boilers, including all the required equipment, as a system which transfers heat to the distribution network through a heat exchanger and an accumulator. This is also the only solution regarding combined power and heating plants, as the boilers are producing steam for the steam turbines.

The purpose of the accumulator is to store heat in order to level off the peaks of the consumption, which also generates more permanent conditions and higher efficiency for the combustion plant.

Consequently, there are usually three temperature levels in a district heating system with connected sub-heating systems. At each heat exchanger the temperature drops a few degrees.

Temperatures below 100 °C are working at a normal air pressure, while temperatures above 100 °C require overpressure to avoid boiling and formation of steam. At temperatures above 100 °C, the systems are classified as pressure vessels, which put greater demands upon material as well as the quality of the workmanship.
As the district heating systems are also responsible for the production of domestic hot water, they have to be in operation throughout the year. A common way to deal with this is to have the flow temperature at a constant level during the summer months, 60-70 °C, which is enough for producing hot water. When the local heating system requires a higher temperature, in order to keep desired room temperature, the primary flow temperature is raised up to the maximum value, according to the outdoor temperature.

The outgoing temperature on domestic water is to be kept as low as possible, preferably below 65 °C. Higher temperatures cause scalding or skin burns.

The legionella bacteria, a malicious bacteria that may cause Legionnaires Disease, sets a lower limit to the temperature on the domestic hot water, 55-60 °C.

Larger systems of domestic water are equipped with circulation so that hot water is available without any unnecessary delay. In these systems, with the help of an automatic control, there is the facilit to run higher temperatures at regular intervals through the system in order to prevent the germ growth.

Primary return temperatures of 60 °C or lower, are desirable whether it is a matter of pure heat production or combined power and heat production. In the first case there is an exhaust gas condenser; economizer, which requires low return temperatures to perform well, and in the second case the condensate has to be cooled down to improve the power production. A large temperature drop also reduces the amount of water circulating in the system, and it also reduces the operation costs for the circulation pump.

6. Expansion systems

The purpose of the expansion system is to manage the volume change of the system water at varying temperatures and to sustain the static pressure level of the system.

Expansion systems can be designed in two ways:
• open or
• closed

Open systems are in direct contact with the environment, while closed systems are not.
In precious years, most of the systems were open, but gradually there has been a change-over to select closed systems. The closed systems can be more easily adapted to changes in the district heating network. Large differences in the elevation within the networks have made it more difficult to work with open systems, as they require sufficient head of water above the production unit.

7. Open expansion system

Normally an open expansion system consists of a tank of the necessary volume with the tank placed higher up than all the other parts of the system.

There are also other cases, where the tank is positioned in the boiler house and a pump fills up or taps off the system as required. The static pressure is sustained because a pipe has been installed to the necessary level.

Open expansion tanks are mostly situated in cold spaces and have to be protected against freezing, which is done by insulation or by supplying heat. A circulation pipe is installed from the boiler up to the expansion tank, and thus the required amount of heat is supplied.

8. Closed expansion system

Closed expansion vessels consist of a tank, in which the required pressure is sustained by air or by nitrogen. Nitrogen is preferable as it eliminates corrosion. A compressor maintains the pressure at the right level.

In smaller systems a diaphragm may be used, dividing the expansion tank into two parts. The heating system is connected to one side of the diaphragm, and on the other side nitrogen is supplied with a suitable overpressure. When the system is filled, the gas will be compressed and while heating, it will be even more compressed. When the water volume changes, due to temperature fluctuating, the gas is adapting its volume.

Safety valves, which opens and lets out excessive pressure if there is any, are required for closed expansion system. The safety valves are regularly tested in order to guarantee this function.
8 STEPS - CONTROL OF HEATING SYSTEMS

Distribution

The distribution part consists of circulation pumps and preinsulated pipes.

1. Preinsulated pipes.
A preinsulated pipe consists of water-bearing pipes, insulation and a construction preventing the ground water from getting in contact with insulation and pipes.

2. Construction, material.
The water-bearing pipe is, as a rule, made of steel. For smaller dimensions, used when connecting to small units, detached houses and so on, copper pipes or pipes made of heat resistant plastic are also used, for example in direct connected systems with lower temperatures.

The greatest risk, as far as the preinsulated pipes are concerned, is external corrosion since there is treated system water in the pipes.

In earlier years the whole heat culvert was built on site. A concrete structure, open upwards, was built in a well drained excavation. The steel pipes, insulated after pressure test, were installed in the structure and then a concrete cover was placed on top. Manholes were placed at regular intervals. The big problem with this type of heat culvert is making the concrete structure leakproof.

The heat culverts of today (preinsulated pipes) are manufactured in a factory with water-bearing pipes of steel, insulation of expanded polyurethane and waterproof pipes of polyethylene. The insulation is foamed between the steel pipe and the polyethylene pipe.

The steel pipes are jointed through welding, and the polyethylene pipes are equipped with divided muffs of plastic-coated plating, fastened with bolts. The muffs are filled with polyurethane foam. Branchings are made in the same way and there is no need for manholes.

Central boiler plant Distribution Consumption

Heat culvert produced on site.
Fig 2:13

Steelpipes, insulation of expanded polyurethane and waterproof pipes of polyethylene.
Fig 2:14
3. Heat losses.
The heat losses from a heat culvert can be considerable if the pipes are not well insulated. The pre-insulated pipes with polyurethane foam as insulation show small losses particularly where there are several insulation thicknesses.

A pre-insulated pipe with a nominal diameter of 100 mm (DN), with an insulation of 35 mm and a water temperature of 100 ºC emits 28.4 W/m under given circumstances. The same pipe with a thicker insulation of 45 mm, emits 23.8 W/m under the same circumstances. The corresponding values for a pipe with the DN of 400 mm and an insulation thickness of 45 and 65 mm respectively is 62.3 and 49 W/m respectively. The same pipe without insulation emits 168 and 203 W/m respectively.

The heat losses are as much as 30% in old heat culvert systems. In pre-insulated pipes the losses are reduced to less than 3%.

4. Linear expansion due to variations in temperature.
The pre-insulated pipes are installed at a temperature way below the normal operation temperature. The pre-insulated pipes are therefore inclined to expand when they are in operation, 0.12 mm/m pipe and 10 ºC temperature rise from the installation temperature. The pre-insulated pipes are working as one unit, i.e. the forces caused by the expansion of the steel pipes are transferred through the insulation to the external plastic pipe. The plastic pipe, in turn, is held in position by the friction against the sand with which it is covered. A linear expansion does not occur, but the wall of the steel pipe picks up the expansion by getting a bit thicker.

Installation and re-filling can be done in several way with regard to the expansive forces, but the final result remains the same:
- no measures taken for expansion pick-up, pre-heating to half of the temperature difference, thereafter re-filling
- no measures taken for expansion pick-up, thereafter re-filling

5. Design.
To design the pre-insulated pipes means an optimization of the pipe costs and the operation cost for the circulation pump. A low water rate gives large pipe dimensions and a low pressure increase across the pump, a high water rate has the opposite effect.

There should be turbulent flow.
The adjustment of the heat supply, applied with two-way valves, results in a varying flow in the pre-insulated piping, which in turn results in a varying flow resistance. The resistance varies by the square of the flow change. If the flow is halved, \( Q = 0.5 \), the resistance is reduced to a quarter, \( 0.5^2 = 0.25 \).

Reducing the flow 5 m³/h, (1), to 2.5 m³/h will reduce the resistance from 60 kPa to 15 kPa, (2). \( 0.5^2 \times 60 = 15 \) kPa.
A reduction to 25%, (3), gives the new resistance \( 0.25^2 \times 60 = 3.75 \) kPa.

Fig 2:17
7. Pumps.
Centrifugal pumps are used in the district heating systems. They are run by electric motors and the sealing around the shaft into the pump housing is a mechanical sealing, which prevents leakage.

8. Pressure control.
The heat supplier signs a contract to supply a certain amount of heat. To be able to fulfil this contract, a lowest available pressure of 100-150 kPa is required at each sub-station.

The available pressure at the sub-station situated farthest away is kept constant with a pressure control, which controls the rotation speed of the pump via a pump control, a frequency converter.

The available pressure is, in spite of the pump control, different at full flow, depending on where the sub-station is connected in the system. The closer to the production unit the higher available pressure. At minimum flow the differences in available pressure are small between the first and the last connected station. The control valves must be sized for this low pressure, and therefore, they are too large at full flow in the system, which may cause problems with a poor control, a high return temperature and a pendulum effect throughout the whole system.

Pressure control, with the sensor at the end of the system, guarantees a minimum available pressure in the system. There will still be big differences in available pressure at different flow.

Fig 2:18

Fig 2:19

Min Δp = 150 kPa
Consumption.
The consumption part consists of heat exchangers for heat and domestic water, with relevant control equipment and heat meters.

1. Heat exchangers.
There are two kinds of heat exchangers:
- coil units
- plate heat exchangers

Coil units consist of flat or profiled copper pipes, wound to a compact unit and is surrounded by a jacket through which the primary medium flows. The secondary medium is connected to the copper pipes.

The plate heat exchanger consists of profiled plates, which are placed against each other so that a space is formed, in which the water is able to flow. Every second space contains primary water and every second one contains secondary water.

The heat exchangers are externally insulated.

The pollutants in the primary and secondary water are deposited in layers in the heat exchangers, due to the rather large temperature differences on the surfaces. Even a very thin layer reduces the heat transfer considerably. Pure water and a high water rate neutralizes the deposit.
2. Connection design

There are many different ways for connecting the various systems to buildings. In principle there are three types:

- direct connection
- one heat exchanger and with a secondary division to the various systems
- a separate heat exchanger for each part of the system

From a safety point of view, direct connection is used only when the flow temperature to the radiators is well below 100°C.

One heat exchanger for all the systems in the building provides great flexibility and excellent possibilities for low return temperatures. Shunt groups with circulation pumps are then installed for radiator-, floor heating- and ventilating circuits. The domestic water is heated in a separate heat exchanger.

When using a separate heat exchanger for each system part, the exchangers can be connected in parallel or the domestic hot water can be heated in two stages. At first the domestic water is heated by the return water from the radiator circuit, and if that is not sufficient, a re-heating takes place by supplying the re-heater with primary system water.
3. Electronic temperature controls.
In heating systems, the secondary flow temperature is controlled according to the outdoor temperature via an electronic control station complete with a sensor a weather compensator. As a rule the control valve is placed on the primary side. The temperature on outgoing domestic hot water is controlled in the same way. The weather compensator has a special control function for this purpose.

The control stations and other electronic temperature controls are often connected to a computer so that monitoring and adjustments may be made from a central location.

4. Self-acting controls.
Self-acting controls have a sensor filled with a substance which changes its volume as the temperature changes. The volume change is transmitted through a capillary tube to an adjusting device placed on a control valve. The adjusting device contains a bellows, and when the bellows changes in volume - expands or contracts - this motion is transferred to the cone in the valve. Self-acting controls can only keep the set temperature constant, and they are therefore not suitable for the control of the variable flow temperature to a radiator system. They are, however, well suited to keep the flow temperature of the domestic hot water or the ventilating air at a constant level.
5. Control valves

The valve capacity is stated as a $k_{vs}$ value, fully open valve. The $k_v$ value states the actual flow, $Q$, in m$^3$/h at a pressure drop across the valve, $\Delta p_v$, at 1 bar (100 kPa).

Two-way valves are always used in district heating systems to prevent more water than necessary from circulating. This means that the flow and the available pressure will vary considerably under varying operating conditions. The variations become more significant the closer the substation is to the circulation pump, even if the pump is pressure controlled.

The valve must be sized for the lowest available pressure existing, 100-150 kPa, minus the resistance across the heat exchanger. If there is too great a difference between the lowest and the highest available pressure, the valve could start to hunt. The valve is too big when the available pressure is higher than the one for which it has been sized.

![Flow chart for sizing control valves](image)
6. Differential pressure control

A differential pressure controller senses the differential pressure between two points in a piping system and can, via two impulse tubes, keep a constant differential pressure by activating a diaphragm and a cone in the valve housing.

If a differential pressure valve is placed in the flow direction after the control valve, with one impulse tube connected before and one after the control valve, the differential pressure across the control valve will be constant, independent of the volume of the flow. Variations in the available pressure, that may occur, will not influence the control valve, even if they are substantial.

A differential pressure controller can serve several control valves, but only one of the valves can then reach optimum conditions.
7. Flow limitation

When a house owner buys heat, he is also contracting for a maximum effect. The heat supplier too wants to make sure that the client cannot consume more. This limitation of the flow is important to the supplier, bearing in mind that he has to be able to deliver to all his clients at the same time.

A constant differential pressure across a fixed resistance causes a limited flow. This can be obtained in several ways. A constant differential pressure is obtained by a differential pressure control valve, and a fixed resistance, which could be a throttle orifice, an adjustment valve or a fully open control valve. A differential pressure control valve with a built-in setting device is also a solution.

If the resistance is fixed - pressure adjusting orifice or fully open control valve – the limitation is done by adjusting the differential pressure. When the resistance as well as the adjustment valve and the differential pressure can be adjusted, the limitation can be done with the help of both the adjustment valve and the differential pressure control. At a fixed differential pressure, (a combined differential pressure controller and an adjustment valve), the limitation must be done with the adjustment valve.
The energy supplied to a building is measured by metering the flow and by registering the temperature difference across the heat exchanger.

The flow meters can be mechanical or electronic, working with ultrasound. Flow and temperature drop readings are accumulated in a computerized unit where the consumption can be read straight away or by using a small computer. The information can also be transmitted through a cable or a modem to a central unit.

Tests have to be made on how to read the consumption in smaller units, in each apartment of a larger building for instance, but this is difficult because heat is transferred between the apartments. (An apartment, located in the centre of the building, with the heat completely turned off, only receives about 2°C lower room temperature than the surrounding apartments.)

In order to keep down the costs for the metering equipment, flow meters are used for the distribution of the total consumption between the different apartments, provided that all the apartments have access to water, holding the same temperature.