Evaluation of systems and products.

The evaluation is based on experiences from systems used in Europe and the systems currently used in China. The results are described in the chapters "Design instructions" as proposals for ready systems. However, a rapid development continues within all fields and new evaluations ought to be made at regular, not too long, intervals.

District heating

District heating means that the combustion, the central boiler plant, including all the required transports, are located at one site, serving a large area. This location should be chosen so that the disturbances of the residents is kept at a minimum, as regards noise, pollutants and transports. District heating systems can be designed for direct or indirect connection. Direct connection is cheaper in the construction process of the system, but in the long run, the whole system becomes more sensitive. A leakage in an installation can even empty the pre-insulated pipes and the central boiler plant of water. The static pressure for the central boiler plant also prevails in the radiators of the apartments. Indirect connection means that the installations of the building form a system completely separated from the pre-insulated piping network by a heat exchanger. In the same way, the pre-insulated piping network is separated from the boiler by a heat exchanger. Each part of the system can therefore work at its own temperature and its own static pressure.

**Recommendation:** District heating with indirect connection should be used.
Central boiler plant

Efficient operation of a central boiler plant requires automatic control and supervision. On the whole, the cost of the automatic controls are the same regardless of the size of the central boiler plant. Automatic control does not become profitable until the produced effect exceeds 50 MW. The efficiency of new boilers of this size is about 88 – 90%. The production of electricity by steam turbines becomes profitable if it is combined with district heating in so-called combined heating and power plants. The boiler effect in the combined heating and power plant should be at least 200 MW. About 40% of the production is electricity and 60% heat. A combined heating and power plant should be in operation all year round. During the winter months, the combined heating and power plant delivers heat to the local district heating networks and uses the return water for cooling the condensate from the steam turbine. Cooling towers are used for condensing of the steam in cases when the district heating network is not sufficient for cooling. During the summer, the heat can also be used to run cooling cycles. The efficiency of combined heating and power plant is about 90 – 92%.

Recommendation: Local central boiler plants should be larger than 50 MW, and they should eventually be connected to a combined heating and power plant of at least 200 MW. Local central boiler plants considered to have a long remaining life, should be equipped with flue gas cooling in order to improve their efficiency.
Fuel.

With modern techniques, it does not matter what sort of fuel you are using since the exhaust gases can always be purified. But a fuel containing less pollutants also emits less pollutants and therefore requires less purification of the flue gases. Coal is a domestic fuel and will therefore be used for the foreseeable future. The local heating plants should be using as pure coal as possible even before renovation or rebuilding. After rebuilding of boilers with a fluidized bed, coal of the best quality should still be used. Coal of a lower quality can be used in the combined district heating and power plants, which have been provided with large scale purification equipment. The quality of the coal should be improved as much as possible before delivery. A reduction of the ash content can be made by washing the coal. This in turn has a great influence on combustion, efficiency and discharges.

Recommendations: All the coal for local heating plants should be of a high quality with low content of sulphur and ash.
Combustion.

Presently, the most efficient method for combustion of coal is the fluidized bed. Combustion can occur at atmospheric pressure or at overpressure. Coal, ground to pieces 6 mm or smaller, is mixed with water or air and then sprayed into the fire, where a glowing and whirling mass is formed, emitting heat to the tubes of the boiler. The temperature in the fire is kept at a constant and relatively low level, about 850 – 870ºC by controlling the supplied fuel amount and the percolation through the tubes. The low combustion temperature results in a decrease of the discharges of SOx to about 400 mg/nm³, about 75% purification. The discharges of NOx are less than 500 mg/nm³.

Recommendations: Small central boiler plants, up to about 40 MW, should be removed, and the pre-insulated pipes should be connected to a larger local district heating network. The boilers in local heating plants requiring a thorough renovation, should instead be replaced by modern boilers with a fluidized bed or gas boilers. New plants are only built with these modern boilers. Smallest size 50 MW.
Exhaust emission control.

The combined heating and power plants which are in operation all year round, should be provided with equipment for thorough purification of the exhaust gases, above all SOx and NOx and particles, but also heavy metals. Equipment for sulphur purification normally removes more than 90% and when it comes to nitrogen oxides, the discharges are lower than 200 mg/nm³. The local heating plants must concentrate on better coal qualities in order to reduce the discharges and also on bag filters to collect the particles. Discharges lower than 5 mg/nm³ are common. When the local heating plants are connected to a combined heating and power plant, the operation time will be considerably reduced and hopefully to under 20%. Under these circumstances the total discharges during one year may be accepted at the present. The local heating plants are thereafter equipped with boilers with a fluidized bed and only used when the production capacity of the combined heating and power plant is not sufficient.

Recommendations: All boilers in local heating plants should, as soon as possible, be equipped with filters to remove the particles from the flue gases, and exhaust gas coolers to increase the efficiency as well as to reduce the discharges of SOx.
Temperatures.
The flow temperature of the water, through which heat exchangers transfer heat to the local pre-insulated piping network, should be 130°C, and the return temperature about 70°C. These temperatures are chosen so that existing systems can be operated under these circumstances.

Recommendations: The flow temperature of the boiler circuit should be 130°C and the return temperature 70°C.

Static pressure.
The constant pressure of the boiler circuit is determined by the present steam pressure and the highest point of the boiler circuit. The steam pressure must be available also at the highest point in the system. At 130°C, at maximum boiler temperature, the steam pressure is 200 kPa (2 bar) and to that must be added the height of the system converted into kPa.

Recommendations: The static pressure should not be higher than that which is technically justified.
Expansion systems.

An open expansion system requires that the tank be placed with its lower edge 20 meters over the highest point of the boiler circuit. Such a placement is difficult to accomplish without having to take expensive measures. In any case, there will be difficulties in accomplishing service and maintenance. A closed expansion system can be placed at any level within the central boiler plant. The only disadvantage is the required supervision and control of the safety valves, and that there is qualified personnel in the central boiler plant, capable of handling the safety valves.

Recommendations: Closed expansion systems should be used where technically qualified personnel are available for supervision and maintenance.
1. Accumulator.
The main purpose of the accumulator is to even out differences between the heat delivered from the boilers and the consumption in the buildings. The heat requirement in a building can vary rapidly when, for instance, the sun shines on a whole wall face, or lights are turned on in the whole building at nightfall. When the local systems are connected, the accumulator can be used to manage a short period with a larger heat requirement, without having to start up another boiler. When the combined heating and power plant is in operation, the accumulator may allow the plant to manage the variations during a twenty-four hour period without the assistance of other boilers. An accumulator is a large tank of water and it must be made for the working pressure of the system. By increasing the volume of the accumulator with the expansion volume required by the system plus 20% for the gas, the accumulator also functions as a closed expansion tank.

Recommendations: An accumulator should be part of every local district heating network, which eventually should be connected to a combined heating and power plant or to other local district heating networks. The accumulator is charged via heat exchangers from the local boiler and from the combined heating and power plant. The accumulator is also used as an expansion system.
2. Temperature.
The flow and return temperatures in the local district heating network should be at 120°C and 65°C respectively. The temperatures are based upon current values for existing systems. The flow temperature can be adjusted according to the outdoor temperature, down to about 70°C when producing domestic hot water, otherwise down to 30 – 40°C, which leads to reduced losses from the pre-insulated pipes.

Recommendations: Flow temperature of 120°C, return temperature of 65°C. The flow temperature should be adjusted according to the outdoor temperature, but all the sub-stations must have access to at least the required heat amount.

3. Static pressure.
The temperature of 120°C requires a steam pressure of 100 kPa (1 bar) in the highest located part of the system. The static pressure makes the level difference, converted into kPa, from the pressure gauge to the highest point plus the steam pressure 100 kPa. The same problem applies with the placing of an open expansion tank as for the local boiler. The accumulator functions well as a closed expansion tank.

Recommendations: The static pressure should not be higher than that which is technically justified. A closed expansion tank should be used.

4. Pre-insulated pipes.
For systems with working temperatures over 100°C, there are today only pre-insulated pipes available, consisting of steel pipe, polyurethane foam and a mantle of HD polyethylene. The systems are highly developed and there are pipes in all required dimensions. Laying and mounting is safe and relatively straightforward. The heat losses in the pre-insulated piping network should be as small as possible.

Recommendations: Pre-insulated pipes should be used. Check all the welding with X-rays, they are pressure vessels. All the systems should be pressure tested with a pressure of 1,3 times the maximum working pressure. A leakage alarm should be installed.
5. Flow.
The type of flow in the pre-insulated piping network, varying or constant, is determined by the way the joint is made where the heat exchangers are connected. A well functioning district heating system implies low return temperatures, which can only be obtained with a varying flow. A two-way valve, increasing or decreasing the flow through the heat exchanger according to needs, provides a low return temperature and varying flow.

Control valves.
There are two and three-way seat valves. The seat valves have a cone working towards a seat. The cone is shaped differently depending on the field of application. We usually speak of the characteristics of the cone, which describes the ratio between the lift height of the cone and the flow change which is the result thereof. In order to obtain a satisfactory functioning in a radiator system, it is a good thing if a certain change of the lift height of the cone in the primary control valve results in the corresponding change of the heat emission from the radiators. For this purpose a cone with a logarithmic characteristic is required. Other characteristics are linear ones, for instance in thermostatic valves, and also exponential ones.

Valve authority.
The valve authority or the pressure authority of the valve states the valves share of the resistance in the circuit where it is placed, 30% for three-way valves and 50% or more for two-way valves. These values are only applicable to the sizing circuit. With regard to other valves the available differential pressure has to be calculated, and the valve should preferably use the whole pressure available to the valve.
Two-way valves.
A two-way valve has one inlet and one outlet, and the cone and the seat are placed in between, making it possible to control the flow through the valve.

Connection.
The design of the connection determines its function.
The simplest connection design is when a pump is feeding water to the valve which increases or decreases the flow as required. When the water has passed the consumer unit, a heat exchanger for example, it returns to the pump. The flow in the circuit will vary. Two circuits are obtained if a shunt is placed after the control valve, between flow and return, and after that a circulation pump. The circuit before the shunt will give a varying flow, when the control valve is adjusting the flow as required, and the circuit after the shunt will have a constant flow with varying temperatures. Whether the control valve is placed in the flow or in the return pipe is of no significance as far as control is concerned, but if the shunt is placed high up in the system, the best situation is to have the valve in the return pipe, which will reduce the risk of air entering the consumer units. A shunt for a ventilation device should be placed as close to the radiator as possible to avoid temperature oscillations. A two-way valve may be used to provide a constant flow in the supply circuit, but in that case a shunt is required before the control valve, in which the resistance is as large as the resistance through the control valve in nominal position. (Since three-way valves already have an automatic shunt in the control valve, they would be the natural choice).

The above shunts with three or two-way valves with no pump in the main circuit give the same result. A pre-setting valve in the by-pass is required when using two-way valve. The resistance in the by-pass should be equal to that of the two-way valve.

Fig. 4:17

More or less flow in the primary circuit controls the temperature in the secondary circuit.

Fig. 4:18

Shunt for control of the temperature in secondary circuit.

Fig. 4:19
Differential pressure control.

In systems with varying flows, large variations arise in the available differential pressure, which means that the control valves, sized for the lowest available differential pressure, are forced to work with a many times larger pressure. At these high pressures the valves become too large and this could easily result in oscillations which, except for unnecessary wear, causes higher return temperatures and affects the other valves in the system. The differential pressure controls keep a constant pressure at varying flows.

Construction.

A differential pressure control consists of:

• valve body
• control unit

The valve body contains a cone and a seat.

The control unit consists of a diaphragm, a setting unit with a spring pack and a connection for impulse tubes on each side of the diaphragm, and also the impulse tubes. An impulse tube can be built into the valve body.

Function.

The differential pressure control can be mounted before or after the part of the system over which it is to control, the controlled circuit. One impulse tube is connected before the controlled circuit and on the positive side of the diaphragm. The other one is connected after the controlled circuit and on the negative side of the diaphragm. Differential pressure controls with a built-in impulse tube are made to be mounted either before or after the controlled circuit.

This combination provides the control valve with the same available pressure when the flow fluctuates.

Fig. 4:22
Flow limitation.
In large systems, there may be requirements for limiting the flow to the connected units, so that none of them can take any flow away from the others.

Principle.
The principle is: The flow is limited by keeping a constant differential pressure over a resistance.

Solutions.
The differential pressure is kept constant with a differential pressure control. The resistance can be a throttle orifice, a fully open control valve or an adjusting valve. There are also complete flow controllers, in which a differential pressure valve and an adjusting valve are built together as one unit.

Recommendations: The flow in the pre-insulated piping network should be varying. Two-way valves should be used for controlling the heat supply to the heat exchangers. Differential pressure controls should be mounted at the control valves and they should also be used for the maximum limitation of the flow, along with the control valve.

Modern district heating systems, with requirements of low return temperatures, work well together with heat exchangers with a small water content.

There are in principle two kinds of heat exchangers:
• plate heat exchangers
• coil units

Both types provide a comparatively small resistance in spite of a high water rate. High water rate is good, because it leaves less depositions in the exchanger.

Recommendations: Plate heat exchangers or coil units should be used.
7. Pump.

Circulation pumps used in district heating systems give a larger pressure increase at lower flows. At the same time, the requirement for pressure is less as the resistance decreases by the square of the flow change. The high differential pressure causes problems at the control valves in the form of noise, poor control and hunting, but it also involves unnecessary electric consumption for operation of the pumps. While the resistance alters by the square of the flow change, the electric consumption alters by the cube of the flow change. Consequently here is money to be saved.

![Diagram of pressure control in heating systems](image)

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 flows.

Fig. 4:26
Principles for pressure control.
There are several principles for controlling the differential pressure provided by a pump:
• constant differential pressure at the last consumer
• constant differential pressure at the pump
• proportional differential pressure
• parallel to the resistance in the pipe system
A constant differential pressure at the last consumer guarantees that all the sub-stations have the required pressure, which gives a lower differential pressure by decreasing consumption, and at the flow of almost zero, the low differential pressure is predominant throughout the whole system. The available differential pressure for valves is determined at a minimum flow. Valves close to the pump will at a maximum flow, have a considerably higher differential pressure than that they are sized for.

Principles for the control of electric motors.
There is one type of control for the electric motors in question:
• a frequency converter
A frequency converter converts the alternating current into direct current and then into alternating current for the moment required frequency. Frequency converters are used together with standard induction motors and are available in sizes from 1,1 – 200 kW shaft effect. The efficiency is high, about 96%, and installation and use are simple.

Recommendations: Pumps on the primary side should be equipped with frequency converters for pressure control. The pumps should be placed in the flow pipe to ensure the water level in sub-stations located high up. The lowest available pressure at the last consumer should be kept constant. The control valves should be sized for this lowest pressure. The problems with large variations remain, though somewhat smaller, considering the available differential pressure at the control valves. Differential pressure control is always a requirement for reliable, safe function.
8. Metering.
Heat meters are used in district heating networks to distribute the costs according to consumption, which is an efficient way of lowering the heat consumption.

Metering can be made centrally for the whole building, and then the costs are distributed according to apartment area.

Principles.
Heat meters for district heating consist of:
- flow meter
- temperature sensor
- counter
There are several kinds of flow meters:
• impeller indicator
• ultrasonic meters

The impeller indicators are the oldest ones, and they consist of an impeller set in motion by the water flow. At small flows, the impeller indicators have great margins for error, and they are sensitive to larger flows than those which they have been sized for. The impeller, its shaft and its bearings are exposed to hard wear by impurities in the water. Regular services are therefore required. Servicing every second year is standard for a district heating network.

Ultrasonic meters have no moving parts, and they work with a sound signal, transmitted to a receiver from where it is transmitted back. The difference in frequency between the two signals is a measure of the flow rate, which multiplied by the pipe area gives the flow. The ultrasonic meters are insensible to impurities and have a large accuracy of metering within the whole metering range, which is considerably larger than the one for the corresponding impeller indicator.

Temperature sensors should be placed in the flow and in the return to meter the temperature drop across the plant.

In the counter, in this case a computer, the temperature drop is multiplied by the flow, and the result is the consumed heat amount. The consumption can be read from the meter, via a modem or a cable, laid in connection with the pre-insulated pipes.

**Recommendations:** Metering of the outgoing heat amount from the central boiler plant, as well as of the heat deliveries to the various buildings, is to be made in order to check the efficiency of the production and distribution. This metering makes it possible to study the effect of different measures taken, but it also gives a signal if something is wrong. For this purpose, ultrasonic meters are presently the only alternative.
Heating systems.

Heating systems is the comprehensive term for all the installations for the heating in a building i.e. the production, the distribution and the consumption unit.

One or two-pipe systems.

The great difference between one and two-pipe systems is the flow temperature to the radiators connected to the circuits respectively, and consequently the resulting return temperature. In the one-pipe systems, the flow temperature becomes lower for each connected radiator, and in the two-pipe systems, the flow temperature is the same for all the radiators, irrespective of the heat losses from the pipes between them. The temperature drop across a one-pipe coil, 20 - 25°C, is the same as the one across each radiator in a two-pipe system, but at an incidental heat gain, the thermostatic valves are closing, and the return temperature then decreases in a two-pipe system, while it increases in one-pipe systems. The flow is constant in one-pipe systems and varying in two-pipe systems. The differential pressure controlling of the pump in two-pipe systems may cut the operation costs for the pump between 70 to 80%. You cannot make that kind of saving in a one-pipe system.

The flow is the same to all radiators in a one-pipe circuit. In two-pipe systems the flow will be determined from required heat and temperature drop across the radiator.

Fig. 4:33
1. One-pipe systems.

The gradually lower flow temperature in one-pipe systems is compensated by the increase of the radiator surface. The surface increases the lower the flow temperature becomes. If the flow temperature decreases below the required value, i.e. the available heat amount is too small, it becomes impossible to compensate by an increased flow.

The heat emission from the pipes in a one-pipe circuit cannot be controlled, and the emission can be substantial especially from uninsulated pipes. If one or several thermostatic valves have closed the flow to respective radiators, the flow in the circuit continues with a higher temperature and the heat emission from the pipes increases. The gravity forces, especially in high-rise buildings, increase the circulation in the circuit considerably. The flow in the one-pipe systems is constant and has to be adjusted for each circuit.

There are roughly 6 meters of uninsulated pipes in each room

Room temperature: 20 °C
Flow temperature: 90 °C

Vertical pipe DN 25
Heat losses: 105 W/m x 0,8 = 84 x 3 = 252 W

Horizontal pipe DN 25
Heat losses: 105 x 3 = 315 W

Sum: 567 W

Fig. 4:34

Heat losses from uninsulated horizontal pipe.
For vertical pipe reduce by 20 %
One pipe above another reduce by 12 %
Three pipes above each other reduce by 20 %

Fig. 4:35
Existing one-pipe systems.
Existing one-pipe systems usually have problems with the distribution of heat between various one-pipe circuits and between the separate rooms.

The distribution between one-pipe circuits.
The distribution between the one-pipe circuits can be adjusted with adjusting valves, providing the available differential pressure is constant. In high-rise buildings, the gravity forces will cause a varying available pressure, depending on the current flow temperature, and then an automatic flow control is required on each one-pipe circuit in order to distribute the flow properly.

Heat emission from radiators.
The heat supply to a radiator is controlled by the flow temperature, the temperature drop and the flow amount.

The heat emission from a radiator is controlled by the difference in temperature between the radiator surface and the air temperature of the room.

If we increase the flow through a radiator from zero, at a constant flow temperature, the heat emission will increase considerably up to a certain temperature drop across the radiator. A further increase of the flow will above this level give a very small increase of the heat emission.

Heat emission from radiator with 90°C flow temperature at 30% to radiator. Small temperature drop means that the flow must be reduced with some 70-80% before there will be a significant change in heat emission from the radiator.

Fig. 4:37
The reason for this is that when the surface temperature of the radiator is almost the same across the whole surface, the heat emission cannot become any larger. It is the difference in temperature between the surface of the radiator and the room air which determines the heat emission. The heat emission will not change if the difference in temperature isn't altered.

A small flow through a radiator provides a large temperature drop. A large flow results in the opposite. It is first at a temperature drop of 15-20°C that a flow change really affects the heat emission.

The temperature drop has to be relatively large, more than 15°C if you want to be able to control the heat emission from the radiators in a one-pipe system.

Flow distribution to the radiators
A flow distribution to the radiators requires a by-pass pipe through where the remaining flow can pass.

It is the difference in resistance between the radiators that determines the flow distribution. A large flow through a radiator requires a large resistance in the by-pass. In cases where the radiators and the by-pass pipes are serially connected in a one-pipe system, the resistance in all the radiators and by-pass pipes are added to the resistance in the one-pipe circuit. The available differential pressure is the same for both radiator circuit as well as by-pass, so the difference in resistance across the circuits respectively is determined by the ratio between the two different flows.

This means that the resistance in the by-pass pipes should, at a 30% flow through the radiator circuit, be 0,3/0,7=0,45 of the resistance in the radiator circuit.

At a 10% flow through the radiator, the resistance in the by-pass pipes should be 0,11 of the resistance in the radiator circuit.

How does the temperature drop across the radiator affect the temperature drop across the circuit?
The temperature drop across the radiator does not affect the temperature drop across the circuit. The emitted heat amount however, affects the temperature drop across the circuit.

If a thermostatic valve should reduce the flow through the radiator, to reduce the heat emission, the result would be a larger temperature drop across the radiator. But the water temperature in the circuit after the radiator will have a somewhat higher temperature because less heat has been taken from the water.
Two or three-way valves.
The heat emission from a radiator in a one-pipe circuit can be controlled by influencing the flow through the radiator. The largest heat requirement, at a design outdoor temperature, is adjusted with the flow temperature and a full flow in the one-pipe circuit and the calculated distribution to each radiator. The flow temperature is then adapted according to the present outdoor temperature. A control valve on the radiator can only decrease the heat supply from the level in question.

The two-way valve in a one-pipe system is to have a low resistance with a size equal to the pipe having a resistance which provides a desired distribution to the thermostatic valve and radiator in question. There are specially made inserts which are pressed down into the by-pass providing a suitable distribution for the valve sizes respectively. The heat emission from the radiators is then determined by the flow temperature and there is no reason for changing the distribution.

Two-way valves are cheap, easy to install and do not require any special settings to function.

A three-way valve in these systems requires an adjustment of the distribution to the radiators, and there must be the same distribution to all the radiators of the circuit in question. When the required adjustments have been made, the functioning is the same for the three-way valve as for the two-way valve with its by-pass pipe. Three-way valves are more expensive, the adjustments are difficult to make in a proper way, and there is always the possibility of changing these adjustments afterwards.

Recommendations: Install two-way high capacity thermostatic valves on all the radiators, with the same dimension as the one of the circuit. Install a by-pass pipe of the same size and equip the by-pass with a by-pass insert which provides the required resistance corresponding to the control valve in question. Equip all one-pipe circuits with flow limiters.
2. Two-pipe systems.

For two-pipe systems, nominal size is applicable as well as the same temperature drop for all the radiators. The thermostatic valves are chosen according to the current flow and the flow temperature determines how large the p-band will be. The resistance across a two-pipe valve and a radiator is normally so large, 5 kPa, that the gravity forces are insignificant.

An increased flow temperature in a two-pipe system means that the thermostatic valves will decrease the flow through the radiators, and the temperature drop becomes larger throughout the whole system. At the same time, the p-band of the valves decreases, which makes the thermostatic valves more efficient. They are, in other words, saving more heat.

The thermostatic valves are maintaining the hydraulic balance in the two-pipe systems as long as they have good heat authority. The available heat amount should be sufficient to keep at least the set temperature. If the flow temperature is decreasing during a twenty-four hour period or more, so that the heat authority becomes less than 1,0, the room temperature will decrease after a while and the thermostatic valves open completely. An adjustment of the flow to each radiator is under these circumstances required to maintain the hydraulic balance.

Two-pipe systems are superior to one-pipe systems. Some advantages are:

- the same nominal radiator size for all the radiators
- a better use of the incidental heat gain
- the p-band is set by the flow temperature
- the return temperature is set by the flow temperature
- a lower return temperature at incidental heat gain
- pre-setting of the flow to each radiator
- easier to adjust at changed operation conditions
- considerably lower operation costs for a pressure controlled circulation pump

![Diagram](image-url)

A higher $t_{\text{flow}}$ 86 instead of 82°C, gives a reduction of the p-band from 1,5 to 0,4°C. That means the thermostat will use more of the incidental heat gain, it will be more effective.

Fig. 4:42

Night set back of the $t_{\text{flow}}$ to any point under the temperature for good heat authority, takes the thermostat out of order.

Fig. 4:43
Vertical or horizontal systems.
Vertical radiator systems imply that the riser is laid at an outer wall, and that one, maximum two radiators per floor are connected to the riser. There are two important disadvantages with this system. For one thing, there are many risers conducting noise between the apartments. Secondly, when using one-pipe systems there are problems in how to limit the number of radiators per one-pipe circuit. One as well as two-pipe systems can be used. There are also difficulties insulating the risers placed visually in the rooms.

Horizontal radiator systems imply that several apartments on the same floor share a riser, how many depending on the planning. The riser can, in this case, be laid centrally in the house and be insulated so that all floors obtain the same flow temperature. The piping to the radiators is installed horizontally on a wall or embedded in the floor and can be installed separately for each apartment as well as for multiples.

When using two-pipe systems, there is the possibility of metering the flow to the radiators in each apartment and also keeping the available differential pressure constant on each floor. The disadvantage is the laying of the pipes to the radiators. Horizontally laid pipes on a wall by the floor or by the ceiling are neither pretty to look at nor hygienic, and near the floor cause problems if doors are to be passed. The casting of pipes into floors requires that the floor construction is made in two steps, one bearing construction, upon which the pipes are laid and one screed laid after having pressure tested the pipes.

Embedded pipes ought to be insulated and require such conditions that they do not need to be exchanged until the building has served its time. One- as well as two-pipe systems can be used.

Centrally placed risers and horizontal laying to the radiators are advantageous, above all when constructing a new building, but this can also be made in existing buildings. Some advantages are:

- a smaller number of risers
- no noise transfer between the apartments
- the possibility of flow metering per apartment
- differential pressure control for each floor
- small radiator circuits reducing the requirement of adjusting
Gravity.

The forces arising due to the differences in water density at various temperatures, gravity forces, become large in high-rise buildings and at high temperatures. There are also great variations due to the current flow temperature, if the flow temperature is controlled according to the outdoor temperature.

In an 18-storey building, the gravity forces are 8.3 kPa at 95°C flow temperature and at 25°C temperature drop. At a heat requirement of 50%, the temperature drop is 12.5°C and the flow temperature 55°C, which gives gravity forces of 3.1 kPa (approximate values).

The pressure conditions in the systems are affected equally, whether it is a question of one or two-pipe systems, or vertical or horizontal ones.

Regarding the one-pipe systems with thermostatic valves, the flow will increase in the one-pipe circuits. The thermostatic valves close a little to preserve the set room temperature, but the flow in the circuit increases and the return temperature becomes higher. The solution to this problem is to install a flow limiter on each one-pipe circuit. Then the flow will remain the same, independent of the variation of the gravity forces in flow temperature and temperature drop. Note that a stationary adjustment does not work because of the varying available differential pressure.

Two-pipe systems with thermostatic valves on all the radiators will also adapt themselves to the new pressure conditions so that the heat supply is preserved. The size of the flow will be the same, as well as the return temperature. You may have a problem with noise disturbance, if the total available differential pressure at the thermostatic valves becomes too high, more than 25 kPa. Thermostatic valves for two-pipe systems can manage a differential pressure of 80 kPa, as far as controlling is concerned. The same conditions are guaranteed, independent of the size of the gravity forces, if differential pressure controls, with a stationary value of 10 kPa, are installed at the bottom of the risers up to the 6th floor, or for the apartments of each floor.

Recommendations: Centrally placed risers, differential pressure control and horizontal two-pipe radiator circuits provide the best conditions to obtain a well functioning system with good possibilities of metering and reducing the heat consumption, as well as cutting operational costs for a pressure controlled circulation pump. This solution can also manage large gravity forces as well as other variations of the differential pressure.
3. Thermostatic or manual valve.
Radiator valves are intended to be used when controlling the heat emission from radiators. There are in principle two types:

- manually controlled
- thermostatically controlled

Manually controlled valves are adjusted by hand when someone finds it too hot or too cold. The flow temperature must be adapted to the outdoor temperature at the building in question with great accuracy. Incidental heat gains from heat sources other than the heating system cause over-temperatures and over-consumption.

Manual valves have very steep characteristics, which make it difficult to adjust to intermediate values. They are either closed or fully open.

Thermostatically controlled valves, thermostatic valves.

The thermostatic valve holds the set temperature, i.e. it detects the room temperature in question and adjusts the heat supply to the radiator according to the current requirement. With the correct setting of the system, (the flow temperature and the constant differential pressure) the thermostatic valve uses incidental gains from other heat sources and overtemperatures are avoided.

A thermostatic valve consists of two parts:

- valve body
- control unit (a thermostat built-in to a construction mounted on the valve body)
Valve body.
There are several kinds of valve bodies, straight and elbow and also different sizes. The sealing around the spindle affecting the cone, is constructed as one unit making it, easy to exchange during operation.

Control unit.
There are several kinds of control units. The most common ones are:
- control unit with a built-in thermostat sensor
- control unit with a separate sensor, connected with a capillary tube

Principle for a thermostat.
The principle for the thermostat is simple. A substance, liquid, wax or gas, is enclosed in a body, and when the substance changes its temperature, it also changes its volume. The body, often a bellows, then expands or contracts, and this change in form is transferred to the valve cone so that the flow to the radiator increases or decreases. Experience has shown that a gas/liquid filled bellows gives the best result and the best safety of operation.

Thermostatic valves are proportional controls, regulating the heat supply in relation to the difference between the temperature set on the thermostat and the temperature detected by the thermostat. If the thermostat detects a much lower temperature than the one set on the thermostat, the valve opens more than if the difference is smaller.

The thermostatic valves should be set at the desired room temperature, and the flow temperature at the valve should be at least so high that the set room temperature can be obtained.

Recommendations: Thermostatic valves with the right valve size, the right control unit, with the possibility to set a maximum temperature and the correct setting of the system (pressure, flow and flow temperature) provide an improved comfort and a reduced heat consumption. A well constructed system can save more than 20%, in one as well as two-pipe systems.
In a heating system with manually controlled valves, it is obvious that the flow temperature must be adjusted according to the outdoor temperature, (the requirement) so that the approximate desired room temperature is obtained.

Function.
A weather compensator consists of:
• control unit
• control motor, control valve
• sensor for outdoor temperature
• sensor for flow temperature
• sensor for return temperature, optional
• timer, optional

The centrally placed control station adjusts the flow temperature according to the outdoor temperature. A sensor placed outdoors on the north side of the building detects the temperature and sends this information to the control station. A curve can be set in the control station, which governs the desired flow temperature at different outdoor temperatures. The control station compares the desired value with the real value via a sensor in the flow pipe. If the two values do not correspond, the position of the cone is altered in the control valve via a control motor.

The controls can also check that the return temperature does not become too high, via a special sensor mounted in the return pipe.

Timers are used to decrease and to increase the flow temperature at certain times.
Why is weather compensation necessary?

It is important that the flow temperature does not become too high for one-pipe systems, as the whole flow in a circuit always passes through the pipe circuit emitting heat to the rooms, even if the heat requirement is zero or very small. The lowest required flow temperature must first and foremost always be available, so that the desired room temperature can be maintained.

The same thing applies to the two-pipe systems, i.e., the lowest required flow temperature must always be available at all the radiators to maintain the desired room temperature. A too high flow temperature causes either losses from pipes passing through rooms which are not supposed to be warm, or over-temperatures in rooms where the thermostatic valves have closed the supply to the radiators.

Setting of the right flow temperature.

The flow temperature providing the worst located room with desired room temperature is the right one. The curve set in the control station gives the required flow temperature at various outdoor temperatures, but there are different ways of setting it. The curve can be parallel displaced upwards or downwards, and it can be made steeper or more flat according to requirements.

The setting of the curve in the control station can be made quite theoretically, but it is better to set it at some degrees below zero and to base the flow temperature upon the actual requirement.

Read the flow temperature, the temperature drop and the room temperature at the worst located radiator. Has the desired room temperature been obtained and is the temperature drop sufficiently large?
Periodic setting-back of the flow temperature.

A setting-back of the flow temperature during a shorter or a longer period of time is made to reduce the heat consumption. A condition for making a saving is a decrease of the room temperature and that it doesn’t take as much heat consumption when resetting the room temperature after a set-back period as it would have, had the system been run without the set-back period.

Buildings accumulate much heat, heavy buildings more than light ones. The accumulation means that it takes a long time before the room temperature drops when the heat has been completely or partly turned off. If a decreased room temperature is obtained, it also means that the temperature of the building body has dropped and that the same heat amount must also be supplied before the room temperature comes up to normal again.

A simple calculation shows that there is almost no saving to be made in a short temperature set back period over one night. We could for instance assume a building with no accumulation, where the room temperature can be lowered from 20°C to 16°C and raised from 16°C to 20°C without any time consumption. If this set back is made for one night, eight hours in such a building, the mean temperature over twenty-four hours will be:

\[(20 \times 16 + 16 \times 8)/24 = 18,7°C\]

The temperature decrease during twenty-four hours is 1,3°C and each degree with a lower temperature is calculated to give a saving of 0,1°C, 5×1,3=6,5%.

If we make the same calculation with a reasonably heavy building; a decrease of the room temperature with 0,4°C takes four hours and the re-heating takes just as long a time, we will receive the following values: the mean temperature during the eight hours will be about 0,2°C lower, 20-0,2 =19,8°C (20x16+19,8x8)/24=19,9°C; The temperature decrease during twenty-four hours will be 0,1°C and the saving 5×0,1=0,5%.

**Recommendations:** Weather compensation has a function in the heating systems with thermostatic valves. It is essential that the heat authority is always kept over 1,0 for the worst located radiator.

A periodical set-back of the flow temperature gives no saving for only one night, but longer set-back periods may be profitable, several days for example. Note that the re-heating period must start in good time, when a decrease of the room temperature has been obtained, and that a higher flow temperature than the outdoor temperature requires is required during the re-heating period.
5. Flow.

Thermostatic valves in two-pipe systems give a varying flow, provided that they have heat authority. It is true that the weather compensator adjusts the temperature according to the requirements, but the incidental heat gains from people, electricity, cooking and the sun are substantial. Besides, there is a certain decrease of the flow temperature between the first and the last connected radiator, despite well insulated pipes. As the last radiator is supposed to have access to the required heat amount, this means that the first radiator has access to much more heat, which is throttled by the thermostatic valve. The thermostatic valve keeps the set temperature, and this fact in addition to all the incidental heat gains gives variations in the flow, in spite of the set flow temperature.

Differential pressure control.

There are large variations in the available differential pressure in systems with varying flows, which means that thermostatic valves sized according to the lowest available differential pressure, are forced to work with many times greater pressure. The valves are too large at these high pressures, and oscillations easily arise, a fact which, except for unnecessary wear, gives higher return temperatures and affects the other valves in the system. The differential pressure controls keep the pressure constant even at varying flows.
Construction.

There are specially designed differential pressure controls for heating systems. One type with a constant differential pressure of 10 kPa and one type with an adjustable differential pressure of between 5 and 25 kPa.

A differential pressure control consists of:

- valve body
- control unit

The valve body contains a cone and a seat.

The control unit consists of a diaphragm, a setting unit with a spring pack and a connection for an impulse tube. An impulse tube is built-in to the valve body.

Function.

The differential pressure control can be mounted in the flow or in the return of the riser or the branch, across which it is to control the differential pressure, the controlled circuit. Usually the mounting is made in the return pipe. An impulse tube is then connected between the flow pipe and the plus side of the diaphragm. The second impulse tube is built-in to the valve body.
Flow limitation.

The thermostatic valves in two-pipe systems are responsible for the flow limitation as long as they have heat authority. It is, should the available heat amount become too small, sufficient to make a rough pre-setting to manage the flow distribution, thanks to the constant differential pressure kept by the differential pressure control.

One-pipe systems have, as a rule, a constant flow and the current flow must be set separately for each circuit which theoretically can be made with a pre-set adjustment valve. As shown above, the gravity forces are large in high-rise buildings and they also vary with the flow temperature and the temperature drop. A manually adjusted valve will therefore in these cases not work, but an automatic flow limiter is required here.

Principle.

The principle is: The flow is limited by keeping a constant differential pressure over a resistance.

Flow limiters for heating systems consists of:
- valve body
- control and setting unit

The valve body contains a cone, a seat and a drain valve.

The control and setting unit consists of a diaphragm, a spring pack and a handle for the setting.
Function.
The flow limiter is mounted in the return pipe and the built-in diaphragm keeps the differential pressure constant at 15 kPa across the cone and the seat. The setting of the flow is made by altering the resistance over the cone and the seat. The valve also has a shut-off function.

Recommendations: The flow will vary in the two-pipe systems with thermostatic valves. Pre-set adjustments are therefore only functioning when the thermostatic valves have no heat authority. A rough pre-setting can be made to manage the distribution at longer set-back periods of the flow temperature.

Differential pressure controls with a pre-set differential pressure of 10 kPa should, in buildings of a maximum six floors, be mounted at the bottom of the risers and in the branches on each floor in taller buildings. The available differential pressure for the riser or for the radiator circuits on each floor will then always be the same, independent of the gravity forces.

Theoretically speaking, the flow in one-pipe systems is constant, but in high-rise buildings, the gravity forces will give a flow, varying with the flow temperature and the temperature drop. Each one-pipe circuit, vertical or horizontal, must therefore be equipped with an automatic flow limiter.
6. Static pressure.
At maximum temperatures below 100°C, there is no requirement for a steam pressure. Only the height of the building/system determines the static pressure.

Expansion systems.
Closed expansion systems with safety valves require regular supervision and control.
They are therefore not suitable since you cannot have qualified personnel available in all the buildings all the time.

Open expansion systems do not require as much supervision and no service, providing they are made of the proper materials. All the expansion systems must always be in open connection with the part of the system from where the heat is supplied.

The circulation pump in the flow or in the return pipe?
A heating system with an open expansion tank is a communicating vessel and the location of the circulation pump, in the flow or in the return, is of great importance.

The open expansion tank has two functions. It is to:
- pick up the volume change of the system caused by temperature variations
- see to it that all parts are filled with water, whether the pump is in operation or not

If the pump is placed in the return pipe, the available pressure, i.e. the static and dynamic pressure put together (the pressure which can be read from the water gauge) will increase at the connection of the expansion pipe to the system. The present total pressure for the expansion system, $p_E$, can be calculated. Then, from the water gauge after the pump, read pressure, $p_1$, reduced by the resistance in the pipe, appliances if there are any, and the level difference up to the connection of the expansion pipe gives $p_E$. $p_E$ converted to meter is equal to the difference in level between $p_E$ and the highest point of the expansion pipe, i.e. at the bottom of the expansion tank. Experience shows that the static pressure should be equal to the highest point in the system plus 65% of the pump head converted into meters. The bottom of the expansion tank should be located at this height.

If the pump is placed in the flow, the available pressure will be lower at the beginning of the expansion pipe, i.e. the water level in the expansion pipe sinks when the pump is in operation.
8 STEPS - CONTROL OF HEATING SYSTEMS

Yet, the whole system should be filled with water even when the pump is not in operation to avoid corrosion, and the bottom of the expansion tank should be placed about $0.5 - 1$ m higher up than the highest point of the system.

**Recommendations:** The pump should be placed in the flow. An open expansion tank is placed in a warm area, with its bottom $0.5 - 1$ m over the highest point in the system.

The expansion system and the heating circuit are communicating vessels. The water level in the expansion system, or the pressure in closed systems, are equal to the level in the circuit when there are no circulation.
7. Pump.

Pressure control of pumps.
Circulation pumps used in heating systems, give a larger pressure increase at lower flows. At the same time, the requirement for pressure is less as the resistance reduces by the square of the flow change. The high differential pressure causes problems at the thermostatic valves in the form of noise, worse control and oscillation, but it involves an unnecessary electric consumption for operating the pumps. While the resistance alters by the square of the flow change, the electric consumption alters by the cube of the flow change. Consequently money is to be saved here.

Principles for pressure control.
There are several principles for controlling the differential pressure provided by a pump:

- constant differential pressure at the pump
- constant differential pressure at the last consumer
- proportional differential pressure
- parallel to the resistance in the pipe system

A constant differential pressure at the pump gives a higher available differential pressure at a decreasing flow, and at a flow of almost zero the differential pressure will be the same throughout the whole system. The available differential pressure for valves and branches is determined at a full flow. At a decreasing flow the differential pressure will increase more and more the farther out in the system you go and valves and branches receive a higher available differential pressure.

A constant differential pressure at the last consumer gives a lower available differential pressure at a decreasing consumption and at a flow of almost zero the low differential pressure prevails throughout the whole system. The available differential pressure for valves and branches is determined at a maximum flow. At a maximum flow the valves and the branches close to the pump will have a considerably higher differential pressure than which they are sized for.
Flow chart showing pump head and resistance in the heating circuit. The diagram to the right shows available pressure for each riser at 50 and 100% flow. \( \Delta p_{\text{dim}} \) shows the lowest pressure available for each \( \Delta p \) control and risers. Fig. 4:70

\[ \Delta p_{\text{pump}} \]

\[ \Delta p_{\text{horizontal pipe}} \]

\[ \Delta p_{\text{available for each riser at 50 and 100% flow.}} \]

Fig. 4:71 Without pressure control.

\[ \Delta p_{\text{pump}} \]

\[ \Delta p_{\text{horizontal pipe}} \]

\[ \Delta p_{\text{available for each riser at 50 and 100% flow.}} \]

Fig. 4:72 Constant pressure control.

\[ \Delta p_{\text{pump}} \]

\[ \Delta p_{\text{horizontal pipe}} \]

\[ \Delta p_{\text{available for each riser at 50 and 100% flow.}} \]
Flow chart showing pump head and resistance in the heating circuit. The diagram to the right shows available pressure for each riser at 50 and 100% flow. 

$\Delta p_{\text{dim}}$ shows the lowest pressure available for each $\Delta p$ control and risers.

Fig. 4:73

![Diagram showing available pressure for each riser at 50 and 100% flow.](image)

$\Delta p_{\text{dim}} = 20 \text{kPa}$

$\Delta p_{\text{dim}} = 40 \text{kPa}$

$\Delta p_{\text{horizontal pipe}}$

$\Delta p_{\text{pump}}$

$\Delta p_{\text{available for each riser at 50 and 100% flow.}}$

Fig. 4:74 Proportional pressure control.

Fig. 4:75 Parallel pressure control.
A proportional differential pressure means that the differential pressure, available after the pump at maximum flow will be reduced to half at a minimum flow. The available differential pressure for valves and branches is determined at a minimum flow. At a maximum flow, the valves and the branches close to the pump will have a considerably higher differential pressure than that which they are sized for.

A differential pressure controlled parallel to the resistance in the pipe system means that the pump curve will run parallel to the system curve, but only down to half of the differential pressure at a maximum flow. The available differential pressure for valves and branches is determined at a minimum flow. At a maximum flow the valves and the branches close to the pump will have a considerably higher differential pressure than that which they are sized for.

Principles for the control of electric motors. There are different types of control for the electric motors in circulation pumps:

- A frequency converter is the most flexible solution.

A frequency converter is used together with standard induction motors and is available in sizes from 1,1 – 200 kW shaft effect. The efficiency is high, about 95%. Installation and use are simple.

Recommendations: Pressure controlling of pumps should be used in larger systems. A constant differential pressure at the last branch provides the best possibility for the largest cut in operational cost for the pump. The pressure sensor is placed at the last branch and is set at the lowest required differential pressure. The resistance of a riser is equal to the resistances across a thermostatic valve with a radiator, the pipes in the riser and the resistance across a differential pressure valve, 8 kPa for Danfoss ASV-P or PV. The lowest required differential pressure at a shunt is equal to the resistances across the control valve, the differential pressure valve and also in the pipes between the pressure sensor and the shunt, should there be any. A frequency convertor controls standard induction motors. Considering available differential pressure at risers and branches, the problems with large variations remain even though somewhat smaller. Controlling the differential pressure is a requirement for good and safe functioning.
8. Metering.

Metering of the heat volume per apartment implies a more personal responsibility for the heat costs but is not as accurate. Someone living in the centre of the building may turn off the heat completely without receiving much lower temperature than his neighbours, while someone having a gable apartment, highest up in the building, will get considerably higher heat costs for the same apartment area. A conversion factor can be calculated, based upon the theoretical heat requirement for apartments with a gable wall and/or roof surfaces, compared to the corresponding apartments without these surfaces.

Flow metering per apartment.

In buildings with insulated, centrally placed risers, and a two-pipe radiator circuit per apartment, the heat consumption can be metered for each apartment with a flow meter, preferably an ultrasonic one, bearing service and precision in mind. The flow meter is placed in an easily accessible position, in the stairwell. It can be equipped with a remote control for metering. An adjustment of the consumption for gable apartments and apartments with a roof should be made.

Heat metering per radiator.

Heat meters, installed on each radiator and providing a measure of the consumption through evaporation, seem to be a simple solution, even for existing buildings. For vertical one-pipe systems however, much heat is supplied from the pipes and can not be metered by using this method. The tenants also have the possibility meter manipulating of the meters and meter reading is also time-consuming.

Recommendations: A heat meter per apartment is the most efficient and safest way of metering the consumption. This method requires two-pipe systems, a separate connection for each apartment.

It is (not) advisable to meter the heat consumption of one-pipe systems with an evaporation meter for each radiator, however there is no other method.

To be consistent the consumption of domestic hot water should also be metered per apartment. A flow meter placed in the stairwell has proved to be the best solution.

To be consistent the consumption of domestic hot water should also be metered per apartment. A flow meter placed in the stairwell is the best solution.