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# Managing a hydraulic system in district heating

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# Managing a Hydraulic System in District Heating

The International Energy Agency, IEA, District Heating and Cooling Implementing Agreement, in its efforts to point to ways to reduce the use of energy, has produced a number of publications dealing with various aspects of implementing and improving district heating and cooling systems. This brochure highlights the management of using low temperatures in a direct district heating system in the Netherlands.

More and more low-temperature systems are in operation in district heating. The advantages are obvious, especially when operating a direct system and a STAG (STeam And Gasturbine combined cycle), combined heat- and powerplant. Low temperatures allow for the cooling of condensers at temperature levels comparable with cooling towers at attractive electricity generating efficiency.
Return temperatures from consumers may be as low as 25-30 °C and may even be cooled down further by partially wasting heat.

If at the same time sufficient storage capacity of heat is included, a STAG powerplant may be operated almost at will, regardless of the discrepancy in demand for electricity and heating.
A STAG plant of limited capacity may be incorporated in a regional or national electricity grid, located near consumers and operated to follow heat demand if and when it occurs at optimum conditions for generating electricity. Such a plant, or several strategically located plants, could be regarded as stand-by capacity replacing older, less efficient powerplants.

When heat storage tanks are located near clusters of consumers, a reduction in piping and pumps will result. Allowing for a lower capital layout and reduced pumping costs.

This report looks at a system where all the above advantages were eventually taken into consideration.
Although some of the advantages were lost in the late implementation of the proper heat source, the overall picture will be of interest to all concerned with planning, operating and implementing district heating systems.

Apart from the obvious advantages in reducing the effect of heating upon the environment, the overall cost of heating could be reduced dramatically by generating electricity at the best possible efficiency, paying for the plant and the necessary adaptions to produce heat. Even more advantageous when governments find ways and means to allow consumption of energy used for heating only at consumer prices in order to force the optimal use of combined heat and power generation.

# Contents

# Summary

Purmerend is a town with presently 60,000 inhabitants growing to 100,000. The town is located 20 km north of Amsterdam, the Netherlands.

In 1980 the town council of the municipality of Purmerend decided to implement a district heating system.

A municipal department was created to build, run and manage the system. At the same time the provincial electricity board decided to build a combined heat and power station (CHPS) from which heat would be sold to the municipal heating scheme at cost.

The present municipal heating system serves 20,400 housing equivalents through a 32 km transport pipeline and 165 km distribution pipelines. The system is equipped with 47 substations. Heat is supplied by a combined heat and power station, capacity 68 MW$_e$ and 65 MW$_{th}$, an auxiliary boiler house (ABH) containing 4 boilers of 16 MW each, four mobile boilers of 3.5 MW for temporary or emergency duties and three decentralized storage tanks of a combined capacity of 550 MWh. The transport pipelines have a storage capacity of 70 MWh.

The system may be expanded to serve 30.000 housing-equivalents. Re-organisation of the power industry brought the CHPS in hands of the regional power company UNA *(NV Energieproduktiebedrijf UNA, the energy production company of the provinces of Utrecht and North Holland and the city of Amsterdam).*

As was the case for many a heating system, the project Purmerend was originally designed and partly laid-out in far too grand a fashion allowing for far greater demand, as well per connection (housing-equivalent) as for the entire system (simultaneity), than would be ultimately required.
This made it possible to change the planned indirect system to a direct system. The indirect system started from a 90/70 regime, i.e. 90 °C input into house connections and 70 °C return. This to be realized through transport pipelines wherein water at a temperature of 125 °C would be delivered.

At the time the first part of the system was completed, it became evident that a direct low-temperature heating system was possible, e.g. at a 90/50 regime. This would allow an equal transport capacity in the same pipelines and at the same pump pressures. Costs in layout, maintenance and heat losses would be considerably lower. Also, this regime corresponds well with the implementation within the system of a CHPS at the highest possible electricity generating efficiency. In addition, direct operation will reduce power required by pumps through upgrading of pump efficiency and consequent reduction of pressure.

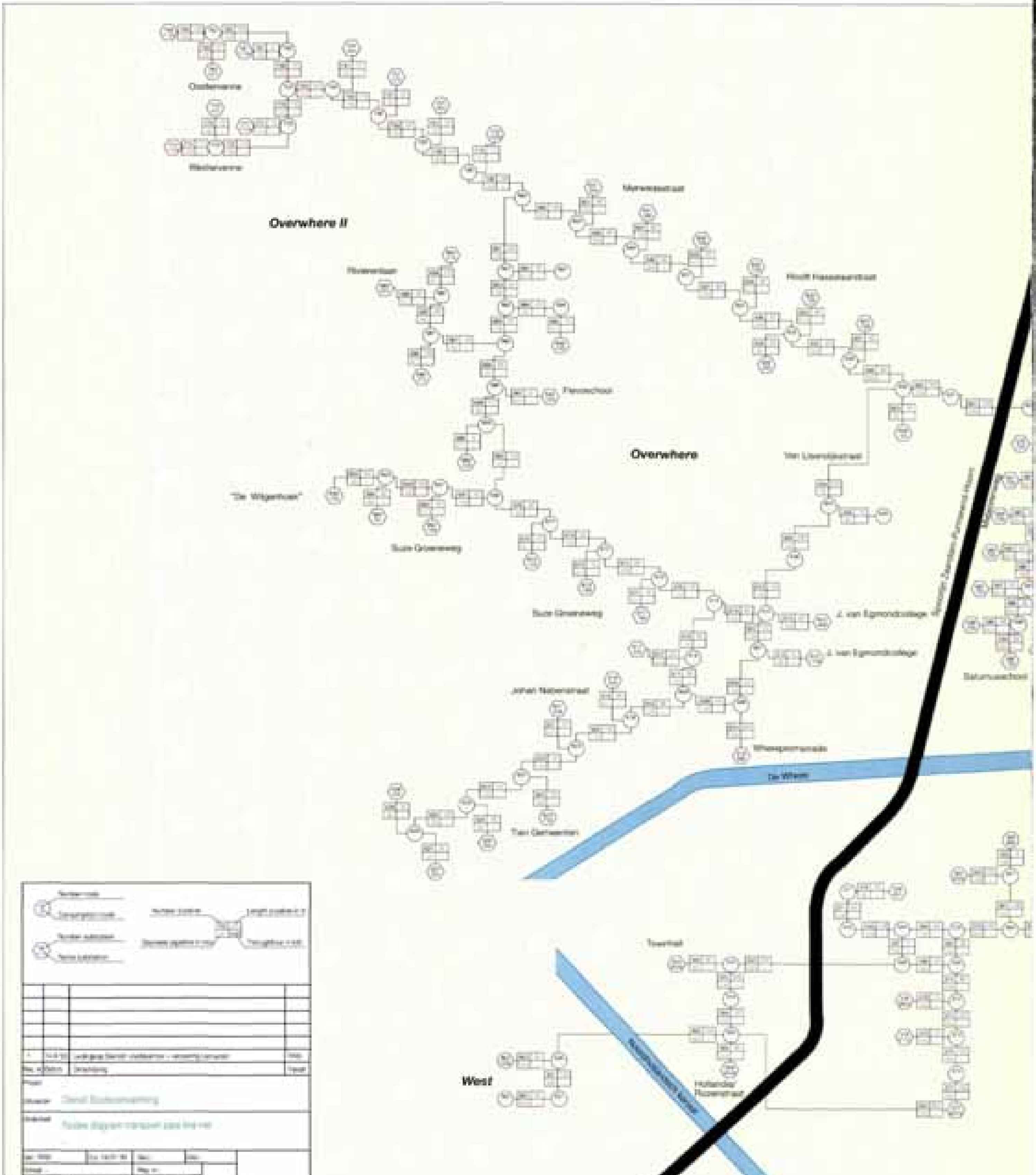
The general conclusion drawn means that application of a direct system requires 15 % less capital investment than an indirect system. Additionally, heat losses and maintenance costs will be lower, upkeep and operation will be simplified.

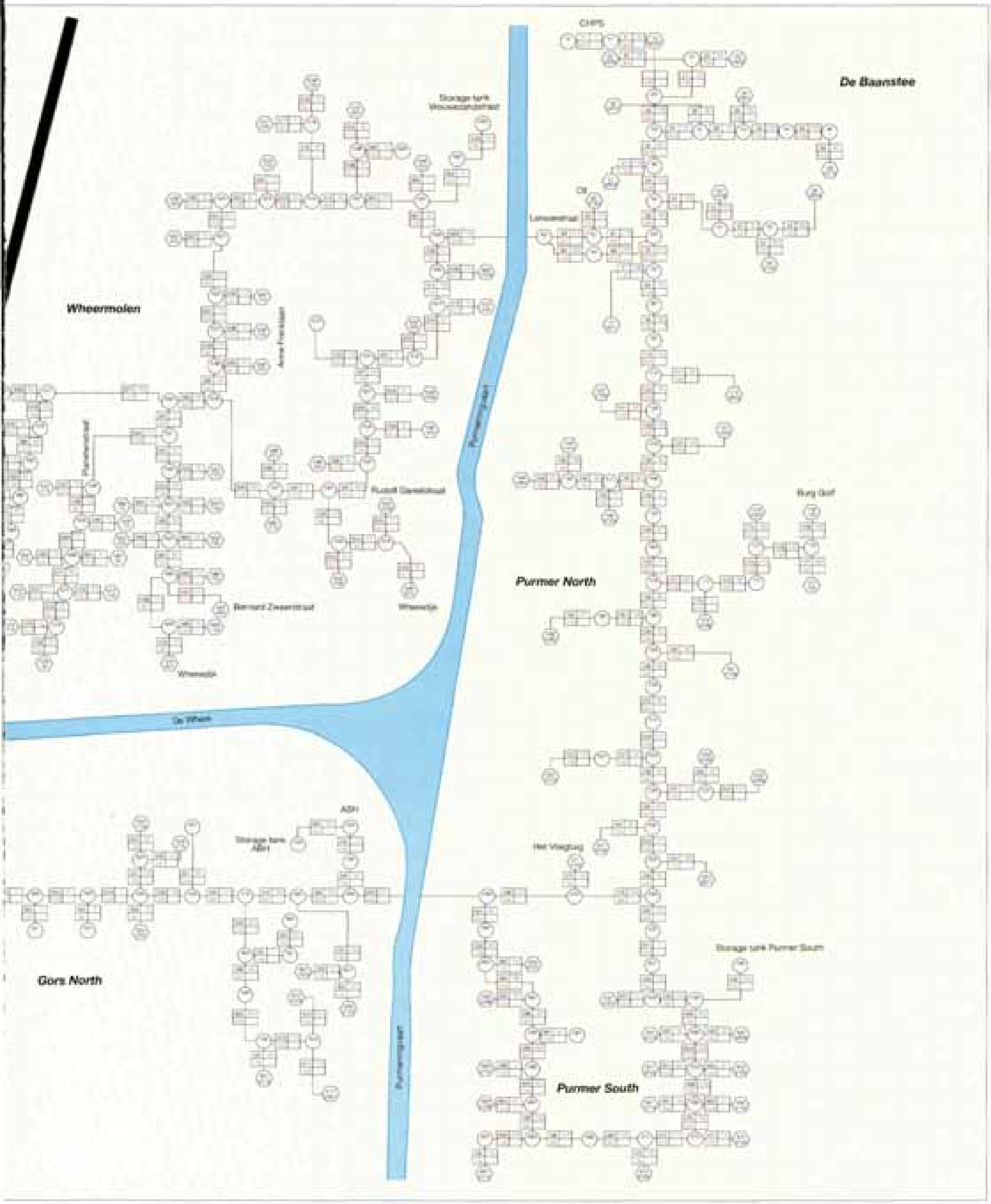
Further reduction of pumping power may be obtained by installing booster pumps. Hereby all required pressure does not need to be supplied at source, giving the opportunity to either reduce pressure or reduce pipe sizes. Optimising of heat supply may be gained by optimal application of auxiliary heat sources and heat storage tanks.

Heat storage tanks have two functions. The first function is that they allow the CHPS to run at full capacity (or not at all) allowing for optimal efficiency. Additionally, this will reduce the number of starts, especially in summertime whereby the plant may only be required to run once every two or three days. The second function is that storage tanks may deliver heat at times of peak demand, thus reducing the maximum size of heat source required.

The obtainable savings in relation to the cost of installing heat storage tanks is so dramatic that consideration will be limited to optimisation. To increase the effect to its maximum, tanks should be situated where their capacity meets demand.

An autonomous control system was designed, incorporating the entire system. When the CHPS produces heat, transport pumps will take hot water out of the storage tank into which the CHPS delivers, and deliver hot water to the transport grid at a pressure of maximum 6 bar. The water level of the storage tank nearest to the CHPS is controlled by a control valve, all other storage tanks by flow balancing. Control of storage tanks and auxiliary boilers is autonomous. All sorts of situations may occur,


Oostervenne
Westervenne
Overwhere II
Overwhere
"De Wilgenhoek"
Suze Groeneweg
Suze Groeneweg
J. van Egmondcollege
J. van Egmondcollege
De Wheeze
Townhall
West
Number node
Consumption node
Number substation
Name substation
Number pipeline
Length pipeline in m
Diameter pipeline in mm
Throughflow in m3/h
DISTRICT HEATING DEPARTMENT


CHPS
De Baanstee
Storage tank
Wheermolen
Purmer North
Burg Golf
Rudolf Dieselstraat
Bernard Zweerstraat
Wheerdijk
De Wheer
ASH
Storage tank ASH
Gors North
Storage tank Purmer South
Purmer South

depending on conditions in the grid. The controls automatically take care of heat storage. Pumps are directed by a compilation of signals found in the grid, pumps located at the CHPS and at the ABH have key-functions.
By use of telecommunication and a central computer, control may be gained by means of altering parameters of the autonomous controls and reactivating local control systems.
Through conditioned parameters, storage tanks may be switched on or off by means of altering values intended for automatic functioning.
Pressure rising, and thus the outgoing flow to the grid, may be changed by altering the relating factor.

By means of well protected modem, public telephone and portable computer, the functioning of the entire system may be called up at any time, any place. Flow-charts and diagrams may be consulted and, whenever required, autonomous controls adjusted.

Overall control depends on the type of users served: one family housing, flats, major users. The controls are adjusted to demand for heating and individual supply of hot water.
Heat consumption is measured individually by energy meters.

The entire transport, distribution and storage system is protected against six potential calamities: high pressure in pumping stations, high pressure in substations and distribution grids, high pressure in return pipelines, overflow of storage tanks, draining of storage tanks and uncontrolled flow into one another.
Moreover, the entire system is monitored, data are collected and stored at 10-minute intervals.
Faultfindings are sorted according to importance, registered and, where necessary action taken by calling up service personnel till satisfied.

Purmerend, the Netherlands
October 1994

# 0. Introduction

## 0.1 Learning from experience

Due to the high energy efficiency of combined heat and power stations (CHPS) at approximately 80 %, district heating is an important option in energy saving policies of local and national government worldwide. The Dutch government induced SEP *(Samenwerkende Elektriciteits-produktiebedrijven or Dutch Electricity Generating Board)* to announce a Warmteplan 2000 *(Heat Plan 2000)*, whereby 1,250 $MW_e$ in new connections are to be realized before the turn of the century.
Previously contracted heating systems provide a wealth of information on design, construction and management as they were implemented. One of those is the district heating scheme of the municipality of Purmerend. This brochure will first pay attention to its concept, in this case soon after its inception drastically changed.

Like quite a few projects started up in the late 70's and early 80's, also Purmerend initially adopted far too great a set-up. Once caught up with reality it proved possible to alter the plans for an indirect system: allowing for 125 °C hot water in the transport supply pipelines and 90 °C in the distribution grids, to a direct system with a supply temperature of 90 °C throughout. This move had a number of advantages.

The preferred fuel-options also changed from heavy oil to natural gas, which again had its consequences and advantages. After sketching this process full of changes, all components making up the Purmerend municipal heating system will be revealed.

## 0.2 District heating Purmerend: its beginnings

The plans on municipal heating date from the late 70's. Then the town of Purmerend was chosen to a nucleus for growth and the task to provide over 10,000 dwellings and subsequent public buildings to go with it. With this appointed task in sight the town council in 1978 requested KEMA, a Dutch research institute for the use of power, to look into the possibilities of district heating and hot water supply on the required scale.

Initially it was thought to obtain heat from the Hemweg power plant in Amsterdam. The municipality of Amsterdam, however, regarded the eventuality of using the available heat within its city limits. Purmerend then considered building a CHPS of its own, to be managed by a newly formed municipal power company. These plans were aborted by PEN *(Provinciaal Elektriciteitsbedrijf van Noord-Holland, the provincial electrical power company of North-Holland)*, being concession holder for all power generation and distribution in the area. PEN, however, proved to be willing to build the required CHPS in the township of Purmerend.

In the meantime KEMA advised positively, as did third parties who were invited to put the advice to the test, and the town council in october 1980 decided unanimously to promote district heating and to make funds available for its creation.

After due consideration of the ways in which to organize the project, the town of Purmerend created a heating services department led by an external director cum project manager.
The department was to run all services as administration, payment collection and debt control, and an upkeep and maintenance division.

Within the department a separate division was established to take care of design, engineering and realisation of the project. The division, under management of the project manager, was manned by externals with the assistance of the chief engineer of the department. The number of persons engaged never exceeded four in total.

The CHPS was build in co-operation with the municipality by the power company PEN. A project team consisting of the heating services department of the town of Purmerend, the power company and NOVEM *(Netherlands Agency for Energy and the Environment)* guided the realisation. Produced heat would be made available at cost to the municipality i.e. the heating services department.

When under government ruling of the late 80's the power-generating companies were restricted to power generation, a new power company was formed under the name UNA, comprising of power companies of the provinces of Utrecht and North-Holland and the town of Amsterdam.

## 0.3 Present state of business

The municipal heating scheme expanded from its humble beginnings to presently 20,400 housing-equivalents. The primary pipeline, now transport line, covers a length of 32 km. (see connection points diagram). The distribution grid has a length of 165 km. The distribution grid is connected to the transport pipelines by 47 substations.

The entire grid may be provided with heat from any of the following sources:

- CHPS, owned and operated by UNA, capacity 65 $MW_{th}$ and 69 $MW_e$. The plant runs at full capacity or not at all;
- auxiliary boiler house (ABH) containing four shell-type hot-water boilers, 16 $MW_{th}$ each. The ABH will be operated at peak demand and be available as standby capacity. Within the ABH there is room for another two boilers. Pumps and piping are already in place;
- four mobile boilers housed in containers, two gas fired and two light-oil fired, each at a capacity of 3.5 $MW_{th}$. These boilers will be set in to (gradually) start-up new developments and in case of emergency;

Moreover available:

- three heat storage tanks at various locations, combined storage capacity 550 MWh. The transport pipelines have a storage capacity of 70 MWh.

Heat generating units and storage tanks may supply heat to the grid in any combination. To be able to boost working pressure in the long-standing townships a (booster)pumping station is incorporated in the transport pipelines. Pumps have as yet to be installed.

Capital investment in boiler houses, storage tanks, substations and pipelines, excluding the CHP plant however, run to NLG 155 million.

### 0.4 Future perspective

The municipal heating system of the town of Purmerend is in no way completed yet. In due time the system will provide heat and hot water to 30,000 housing equivalents with an average connection value of 10 kW and a combined peak demand of 148 MW. The transport pipelines will be extended to 142 km and the distribution grid to a length of 182 km. This extension will require another booster pump station.

Next to the CHPS a second 60 MW ABH will be situated, to allow for down-time of the CHP plant, together with a fourth 1,600 $m^3$ storage tank. Some of the boilers in high-rise flat blocks in the long-standing township will be kept in working order at so-called bivalent connections, 16 MW will thus be automatically available whenever required.

Major extension will start in 1996 with a completely new development consisting of 6,000 houses and subsequent public and other buildings.

Capital investment of the latter is estimated at NLG 36 million, bringing total investment to NLG 191 million.

# 1. Modifications applied

## 1.1 From an indirect to a direct system

Initially it was intended to heat the distribution grid of the Purmerend scheme indirectly.
Hot water would be carried into substations at a temperature of 125 °C and a pressure of up to 12 bars. Heat exchangers would reduce the temperature to 90 °C, as is common for heating, and the pressure in the distribution grids would be kept at a maximum of 4 bar.

Like most district heating schemes, Purmerend started out in far too large a set-up. From early actual consumption-statistics and gathered experiences elsewhere it soon became apparent that actual heat demand proved to be substantially lower than had been estimated. Also, the simultaneity factor (applicable to the maximum demand at any time) turned out to be far different from its adoption in the early design stages.

Besides, the intended 90/70 temperature regime would, certainly during the winter period, result in a return temperature of minimal 75 °C.

Within these temperature ranges the overall efficiency of the scheme would be rather low. First of all because the CHP plant would require a further cooling down (ideally the return temperature would not exceed 45 °C), and secondly because no use can be made of the latent heat in the fluegases of gas-fired boilers.

Fortunate circumstances proved the already installed pipes with diameters of 600 and 500 mm too large in relation to the lower actual heat demand. This offered the opportunity to operate the scheme at a lower temperature regime with its accompanying increased flow and made an indirect system superfluous.

Although six substations had already been built and fitted with heat exchangers, the switch to a direct system was made. The maximum supply temperature in the transport pipelines would be limited to 95 °C at maximum cooling down of the available flow. In winter heat would be supplied at consumer points at 90 °C, to be cooled down by increased energy extraction to under 50 °C.
The transport capacity of the main pipelines would thereby remain at the design level.

Increased energy extraction and subsequent further cooling down of the available flow necessitated larger converters (radiators and/or convectors). These were installed in all houses and buildings after the initial connection of the first 1.000 dwellings to the system.
The first two gas-fired 16 MW boilers were fitted with fluegas condensers and the substations were converted to a different task: from transforming stations to relay stations.

The advantages of the conversions carried out are evidently:
- low temperature/low pressure pipelines do not require government approved testing under steam codes, not even for larger diameters and increased pressure, as the operating temperature will remain below 110 °C;
- stress design, and consequent expansion provisions, are made easier
- at equal heat losses insulation may be reduced, or equal insulation will lead to reduced heat losses;
- loss of insulating properties through aging will develop slower or be of no consequence at all;
- direct substations do not require heat exchangers, circulation pumps or expansion vessels; controls may be simplified;
- pressure rating of boilers may be reduced;
- transport pumps may be of lower pressure rating and light construction;
- standard heating equipment, valves and controls may be used in virtual all cases, pressure rating PN6 will suffice.

Capital layout for realized direct connections proved to be significantly lower than for the initial design. This will be clear from the comparison of cost in table 1 (next page).

The table refers to the following evaluation:
- prices 1992
- 20,000 housing-equivalents in an area of 11 km$^2$
- transport pipelines within the area
- main source of heat located at the edge of the area served
- auxiliary boiler house located in the centre of the area
- 13,000 one-family houses in subsidized building blocks
- 4,000 flats in high-rise buildings, 85 flats per connection
- 1,000 dwellings free-standing and semi-detached
- 2,000 housing-equivalents in shops, schools etc.
- on average, 400 housing-equivalents per substation
- high-rise buildings directly connected to

transport pipelines
- individual domestic hot water heat exchanger in all houses

| | Indirect | Direct |
|---|---|---|
| Design and supervision | 490 | 238 |
| Auxilary heat boilers: | | |
| buildings | 115 | 115 |
| boilers | 225 | 165 |
| pumps and pipes | 102 | 81 |
| Transport: | | |
| transport lines | 1,610 | 1,420 |
| transport pumps | 36 | 26 |
| Substations: | | |
| buildings | 145 | 51 |
| heat exchangers | 51 | |
| expansion loops | 12 | |
| control, pipes, pumps | 214 | 89 |
| communication | 15 | 15 |
| Distribution: | | |
| pipelines | 2,400 | 2,400 |
| heat meters | 500 | 500 |
| extra cost heat bodies | p.m | p.m |
| **Total per housing equivalent** | **5,915** | **5,100** |

*Table 1. Overview of costs indirect versus direct heating systems in NLG per housing equivalent.*

For the first 800 houses compensation was paid to the tune of NLG 180.– per dwelling in regard to larger convertors. Subsequently no further payment was required as a 90/50 regime was prescribed.

It may generally be concluded that a direct system requires a 15 % lower capital investment than an indirect system. Additionally, heat losses and maintenance costs will be lower, upkeep and maintenance will be simplified.

### 1.2 Effects of a direct system on pumping power

The change from an indirect system to a direct system reduced the once needed pumping power considerably. This is firstly caused by a higher efficiency of the pumps. There is no longer need to pump water through heat exchangers in substations. Besides, in a direct system the pressure in the total heat distribution network, including the consumer connections, will be generated by transport pumps. While transport pumps in an indirect system solely generate pressure for the transport network and need smaller circulation pumps to provide the required pressure in the distribution grid, a direct system will make full use of larger, more efficient transport pumps only. This improvement reduces the need for pumping power by 10 to 20 %.

Secondly an even higher reduction of pumping power is realized by lowering the systems pressure to 1.2 bar. Booster pumps in the most distant substations may provide the required return pressure from the distribution network. Finally, lowering the initial starting pressure at the head of the system, from 12 to 7 bar in combination with the aforementioned, results in a 50 % reduction of required pumping power.

Further reduction of required pumping power may be realized by installing booster pumps in special booster pump stations. If the resistance in the total piping system must be met by one pressure point, a relative high pumping pressure is needed. Installing booster pumps at well-chosen locations in the transport pipelines, initial pumping pressures or piping dimensions may be lowered. One booster pump station already is integrated in the transport net. Its use will depend on future expansion.

### 1.3 Effects of a direct system on required heat supply and the piping network

There were two options for the CHPS, to be situated in the Purmer-North. The first option was a conventional oil fired steam power plant with a capacity of 110 $MW_{th}$, the second diesel power generators with a total capacity of 68 $MW_{th}$. Both to be fired with heavy fuel-oil, as part of the fuel diversification policy of the government. Next to the CHPS, a boiler house to a maximum capacity of 116 $MW_{th}$ would be installed, to be fired with heavy oil too. A further gas-fired two boiler houses were planned in the districts Purmer and Gors-North with a capacity of 60 $MW_{th}$ each.

In total 11,800 housing equivalents would be provided with heat, with a mean connecting value of 13.22 $kW_{th}$, and 35 MW in existing apartment buildings. This makes a total connected value of 191 $MW_{th}$. The simultaneity factor would be 80 %. These data were used to compute the dimensions of the main pipeline, bearing in mind that a pressure difference of 1 bar would be provided at the substations to conquer the resistance in heat exchangers and control equipment. Next was the decision to construct the main pipeline in stages, according to the development of the construction of dwellings.

The main pipeline would exist of the following sections departing from the CHPS:

| | |
|---|---|
| pipeline trace DN 600 | 1,450 m |
| pipeline trace DN 500 | 1,570 m |
| pipeline trace DN 450 | 25 m |
| pipeline trace DN 400 | 1,425 m |
| pipeline trace DN 300 | 2,100 m |

Also the location of the majority of the substations was decided well in advance.

Because soon was concluded that heat consumption would be much lower than assumed, in 1981 it was decided to concentrate both the ABHs of Purmer and Gors-North at one location with a capacity growing to just 90 MW$_{th}$. The boiler house was put in operation at the end of 1982 with two boilers of 15 MW$_{th}$ with a concession pressure of 16 bar. A pressure system within the boiler house provided a constant system pressure of 4 bar. Until the end of 1988, when the CHPS was set in operation, this ABH provided all the heat needed for the heating system of Purmerend.

The next decision concerned the construction of pipelines: the main pipeline would be split, thus dimension smaller than DN 300 would suffice. These dimensions are outside the regulations of governmental testing according to steam codes, which meant a substantial reduction in costs. Then followed the decision to build a direct heating system.

To check the size of the distribution system the following calculations were made:

- In the existing system with indirect supply, heat demand (estimated at 152.8 MW$_{th}$ max) would be fully covered by the CHPS with a capacity of 110 MW$_{th}$ and a ABH, in the same location, with a capacity of 42.8 MW$_{th}$. At the initial outgoing pressure of 12 bar required at the highest possible flow of 745 kg/s this required pumping power of 1,127 kW (figure on page 14)

- The option was a CHPS with a capacity of 68 MW$_{th}$ next to a ABH of 40 MW$_{th}$ and the two originally planned ABHs elsewhere. A flow of 574 kg/s would suffice from the CHPS location with an outgoing pressure of 8.3 bar and a total pumping power of 770 kW.

- For the new direct system there are totally different figures. Heat demand could be limited under all circumstances to 5.5 kW per housing equivalent. A simultaneity factor of 65 % would suffice in all cases with a mean connecting value of ca. 10 kW$_{th}$. With 20,000 housing-equivalents this totals to an utmost demand of 130 MW$_{th}$. Based on these figures plans were changed. The preferred temperature regime for the transport system of 95/45 and a systems pressure of 1.2 bar resulted in a necessary flow of 622 kg/s and an outgoing pressure at the CHPS of 5.5 bar which required pumping power to the tune of 330 kW. (figure on page 15)

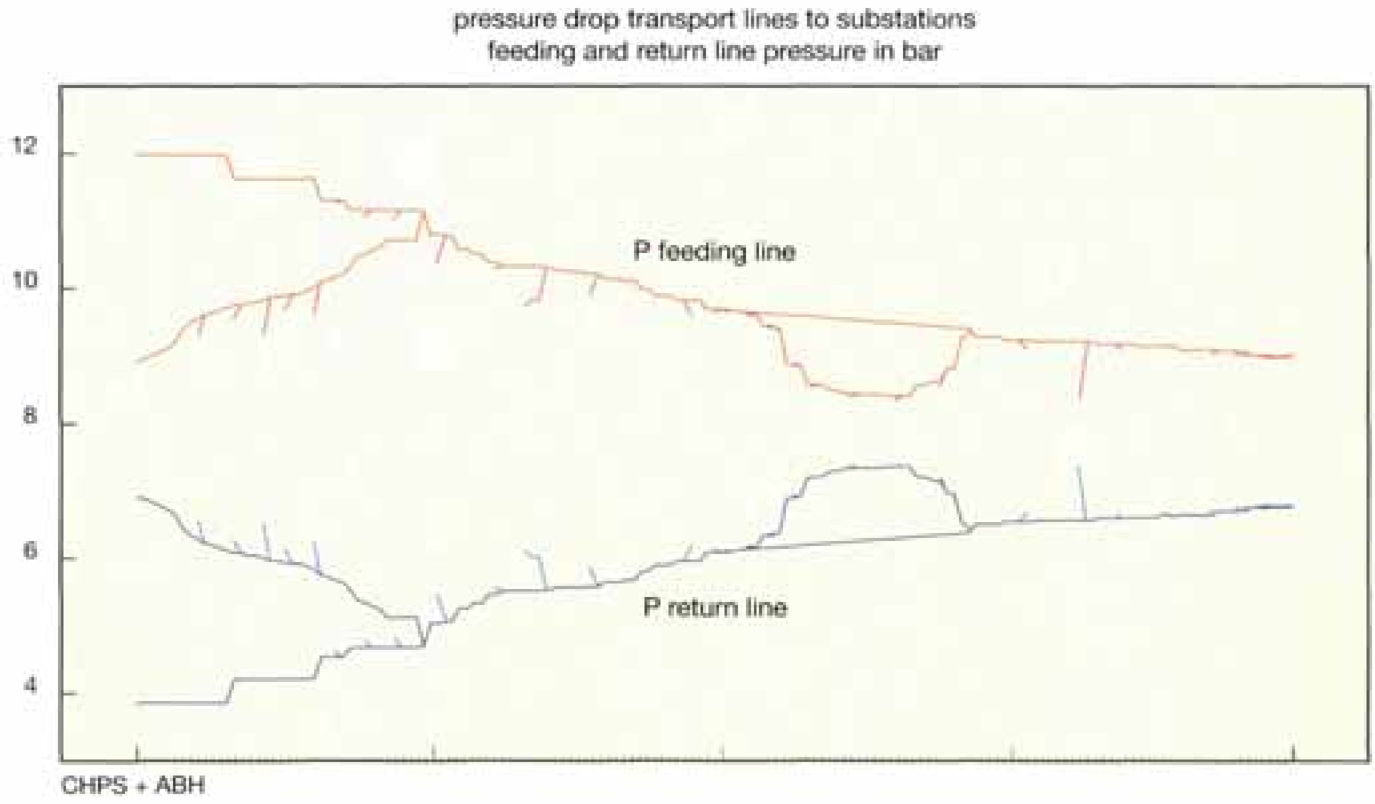
- The system had no need to be adjusted for direct heat supply. Calculations were made to work out what would happen if the CHPS went unexpectedly out of service. It appeared that the ABH in combination with some bivalent connections (using existing relatively large boilers in apartment buildings) should provide a capacity of 123 MW$_{th}$. The outgoing pressure should be 12.8 bar and needed pumping power of 1,055 kW. That was no barrier to change to a direct heating system.

The new data which sounded the decision for a direct system had another effect. The lower heat demand per housing equivalent allowed for a strategic location of mobile boilers and the use of buffers and bivalent connections. There was no need to install more boilers in the ABH.

## 1.4 Necessity of heat storage when using CHPS

Leaving the principle of diversification of fuel it was possible to choose a steam and gas turbine (STAG or combined cycle) CHPS. That happened late in 1985. This type of installation has the restriction of full electrical efficiency only at full power. That gave the reason to pay attention to heat storage. Heat storage allows for optimizing the production of electrical power and to continue heat supply when demand is low, too low for efficient heat production.

The planned CHPS has a capacity of 65 MW$_{th}$. This suffices for heat distribution on a cold day. Heat demand around the average day varies from 46 to 175 % of the mean heat demand. The CHPS is required to supply a maximum of 110 MW$_{th}$. A storage capacity of 3,000 m$^3$

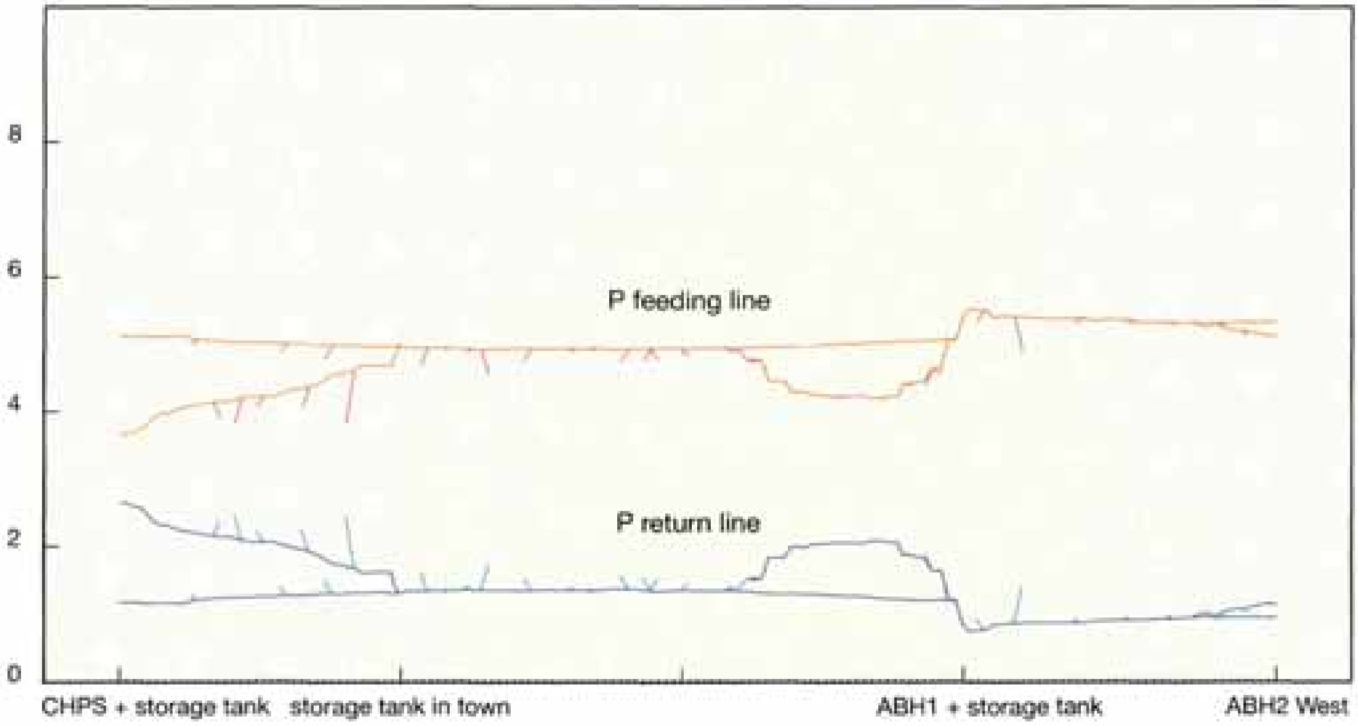

pressure drop transport lines to substations
feeding and return line pressure in bar

design pressure 1981, indirect system

**supply: from one point: CHPS location**

| 14.500 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING EQUIVALENTS | | $MW_{th}$ | kg/s | $m^3/h$ | bar | kW |
| connection value | | 191.0 | | | | |
| simultaneity | 80.0% | 152.8 | 745 | 2,683 | 12.0 | 1,127 |
| feeding temperature | 125 °C | | | | | |
| return temperature | 75 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 110.0 | | | | |
| ABH at CHPS location | | 42.8 | | | | |
| sum CHPS location | | 152.8 | 745 | 2,683 | 12.0 | 1,032 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 8.4 | |
| highest return pressure return transport line | | | | | 7.4 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 95 |

pressure drop transport lines to substations
feeding and return line pressure in bar



design pressure 1983, direct system

**Supply: by CHPS and combined ABH1**

| 20.000 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING EQUIVALENTS | | $MW_{th}$ | kg/s | $m^3/h$ | bar | kW |
| connection value | | 200.0 | | | | |
| simultaneity | 65% | 130.0 | 622 | 2,239 | 5.1 | 327 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 45 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | | 0.0 | | | |
| sum of CHPS location | | 65.0 | 311 | 1,120 | 5.1 | 156 |
| storage tank 2 located in town | | 0.0 | 0 | 0 | 4.7 | 0 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 3.8 | 0 |
| storage tank 3 at ABH1 location | | 0.0 | | | | |
| ABH1 | | 65.0 | | | | |
| sum ABH1 location | | 65.0 | 311 | 1,120 | 5.5 | 171 |
| ABH2 West | | 0.0 | 0 | 0 | 5.3 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 3.6 | |
| highest return pressure return transport line | | | | | 2.7 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

supports this. A heat storage tank was constructed.

Further storage capacity was needed to minimize the number of starts. Production and idling times of long duration are worthwhile. The storage capacity can be situated strategically in the distribution network. When the distribution network is not fully used, electricity to transport heat to the storage tanks is available at relative low cost. At peak demand, when the storage capacity is put to work, only relatively little pumping power is needed.

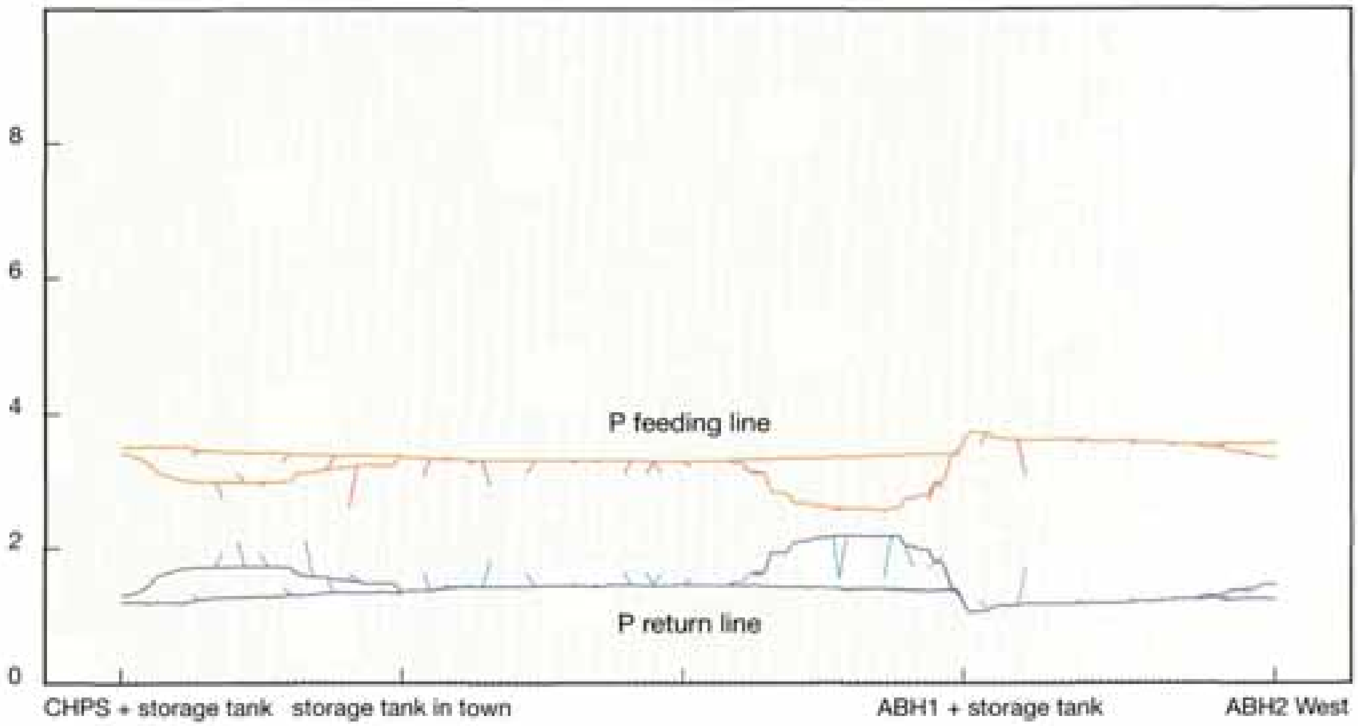
### 1.5 New decisions in regard to system pressure

In the next phase decisions were made in regard to system pressure. Concluded was that at a maximum flow of 2 m/s in the main transport pipes, the pressure in the last substation should be at least 2 bar. Than no further increase of pressure is needed in the distribution grid.

The required 2 bar pressure is needed for:
- 0.3 bar to overcome resistance in control equipment and filters in relay/substation;
- 0.4 bar to overcome friction in the pipes of the distribution grid;
- 0.3 bar to meet the pressure drop of hot water units and space heating units;
- 1 bar system pressure.

To prevent a higher pressure than 4 bar at the users, the system pressure at the substation is limited at 4.3 bar. The pressure in the transport pipes may be higher. This pressure is partly reduced by narrow branch pipes to the substations, partly by throttle valves. The highest return pressure is determined by the friction of the return transport pipes. Without the use of return pumps a pressure drop of 3 bar is just about acceptable. In practice the pressure depends entirely on the water level in the storage tanks.

pressure drop transport lines to substations
feeding and return line pressure in bar



design pressure 1983, direct system

**Supply: by CHPS, ABH1, bivalent connections, active local pumps**

| 20.000 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING EQUIVALENTS | | $\mathrm{MW_{th}}$ | kg/s | m$^3$/h | bar | kW |
| connection value | | 200.0 | | | | |
| simultaneity | 65% | 130.0 | 622 | 2,239 | 3.5 | 197 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 45 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | | 0.0 | | | |
| sum of CHPS location | | 65.0 | 311 | 1,120 | 3.5 | 92 |
| storage tank 2 located in town | | 0.0 | 0 | 0 | 3.2 | 0 |
| Vennen, bivalent connection | yes | 3.5 | 17 | 61 | 3.3 | 4 |
| storage tank 3 at ABH1 location | | | 0.0 | | | |
| ABH1 | | 57.9 | | | | |
| sum ABH1 location | | 57.9 | 277 | 998 | 3.7 | 88 |
| ABH2 West | | 0.0 | 0 | 0 | 3.5 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 2.5 | |
| highest return pressure return transport line | | | | | 2.2 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 13 |

# 2. The main heat source

## 2.1 Selection procedure

At the selection of the main heat source four options were considered. KEMA initially advised the application of an oil-fired extraction/back-pressure steam turbine plant. The resulting cost of heat from such a plant proved to be undesirable.

Next, the possibilities of a mixed fuel plant were considered. This plant would operate diesel engines running on natural gas and/or heavy fuel oil. The plant could have been build in stages, following the development of the heating project. Although this solution was the economically most desirable, it was not achievable because the oil companies predicted that in future only imported fuel oil with a high sulphur content would be available. This was connected with the application of flexi-cookers at the refineries in the Netherlands.

Purmerend researched the introduction of firing refuse derived fuel (RDF) offered in pellets by Icova of Amsterdam. Adoption of this fuel, mainly consisting of wood particles and chlorinated paper, seemed well feasible in a combination of fluidized bed combustion and wet scrubbing of fluegases. A permit was obtained to run a 10 MW pilot plant which would produce heat at a cost of less than NLG 5.- per GJ.

In the meantime the principle of fuel-diversification in district heating had been abandoned. This freed the way to apply a gas-fired CHPS based upon a gas-turbine-fluegas-boiler-steam-turbine configuration. The cost of heat produced, at the then applicable rates of compensation, was calculated at approximately NLG 10.- per GJ.

Concurrently SEP decided to change the compensation system. This resulted in significantly lower, acceptable cost of heat. By the end of 1986 it was definitely decided to change over to the construction of a steam and gas turbine CHPS.

Due to the pressure of time, PEN decided, in conjunction with the municipality, to copy the concept of the CHPS of the district heating system of Almere, where at the time Brown Boveri Company (now ABB) had a plant under construction. Early 1987 the order for Purmerend was placed. The plant had to be completed, on turnkey basis, by the end of 1988. Capital investment, including the heat transfer pumps, ran to the amount of NLG 105 million.

During the construction period the plant was handed over by PEN to UNA under government induced reorganisation and separation of power generation and power distribution. This not only put the "at cost" arrangement under pressure but also led directly to an increase in running cost of the plant. PEN used to be a fully integrated generating and distributing company which could make optimal use of peak shaving and which could supply electricity for starting up and dead-time needs at cost.

UNA, as a solely generating company, must supply to the national grid at fuel cost plus a contribution toward capital- and running expenses decided by SEP and, when in need, must pay the local distribution company PEN for electricity taken out of the grid at users price.

## 2.2 The CHP station

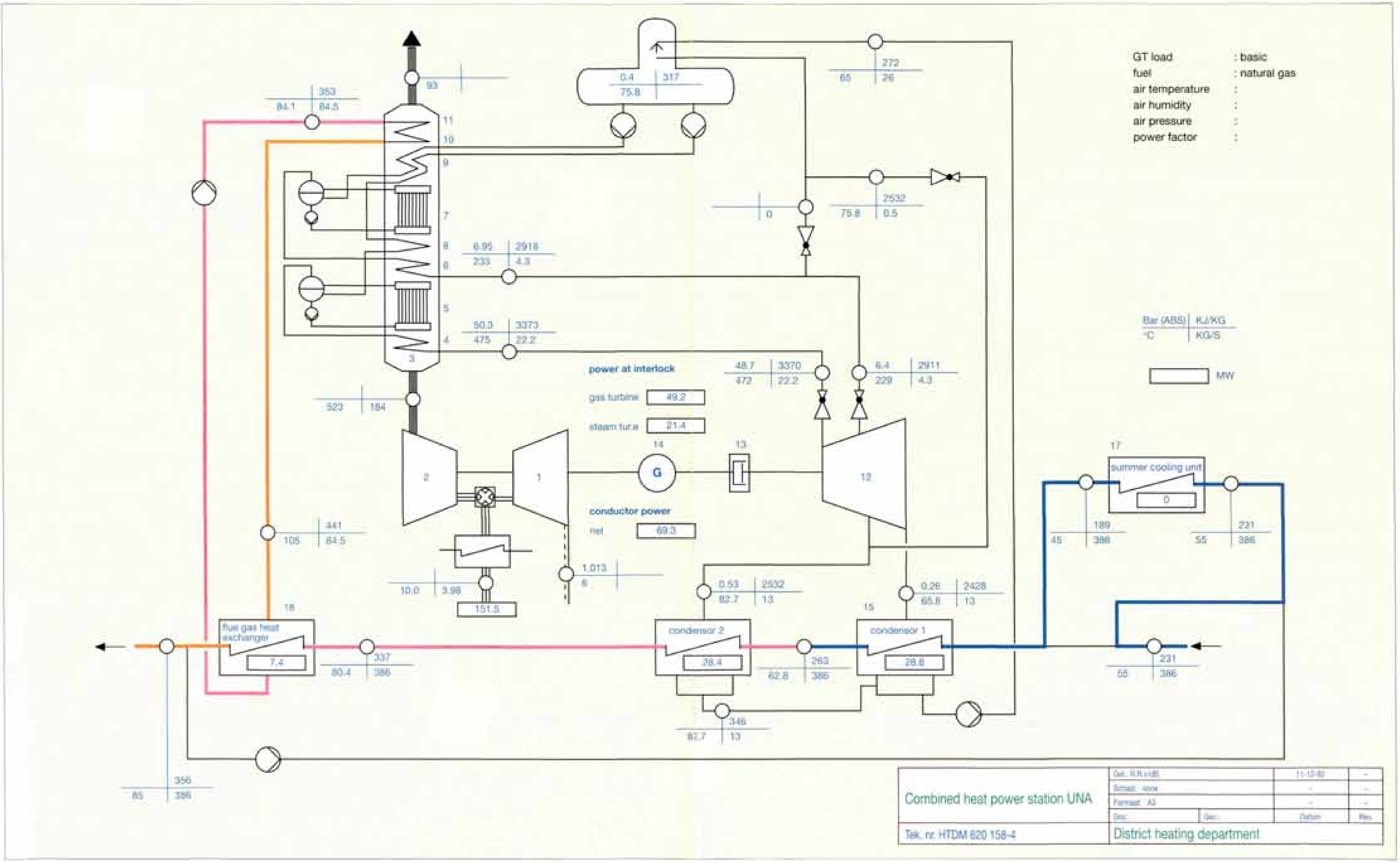
The CHPS, capacity 65 $MW_{th}$ and 68 $MW_e$, incorporates:

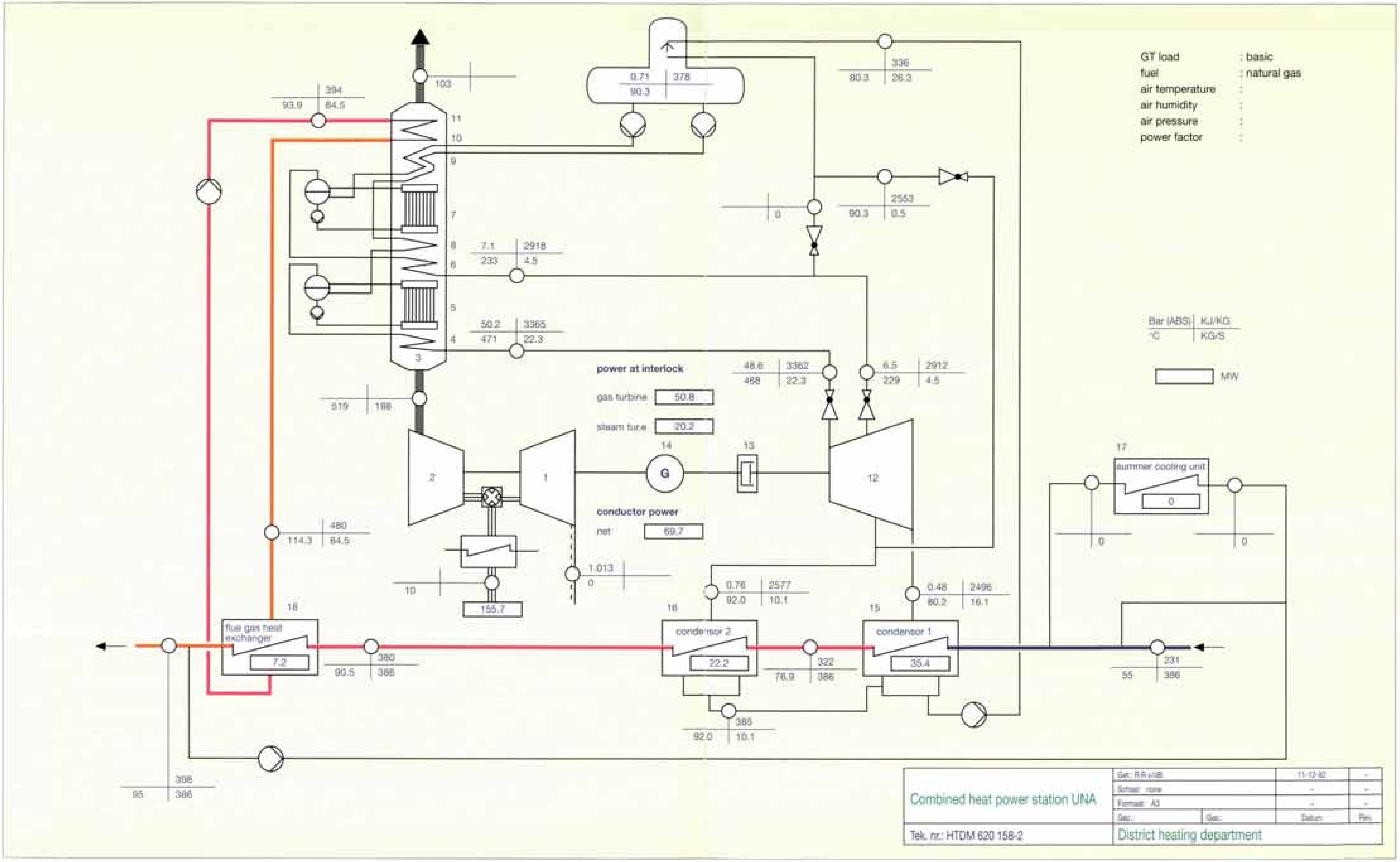
- a gas turbine with its fuel-, air- and exhaust systems
- an exhaust boiler with its steam-, condensate- and feed-circuits
- a steam turbine with condensers and cooling system and an auxiliary cooling system
- a generator directly connected to as well the gas turbine as to the steam-turbine by means of a gearbox and an overriding clutch.

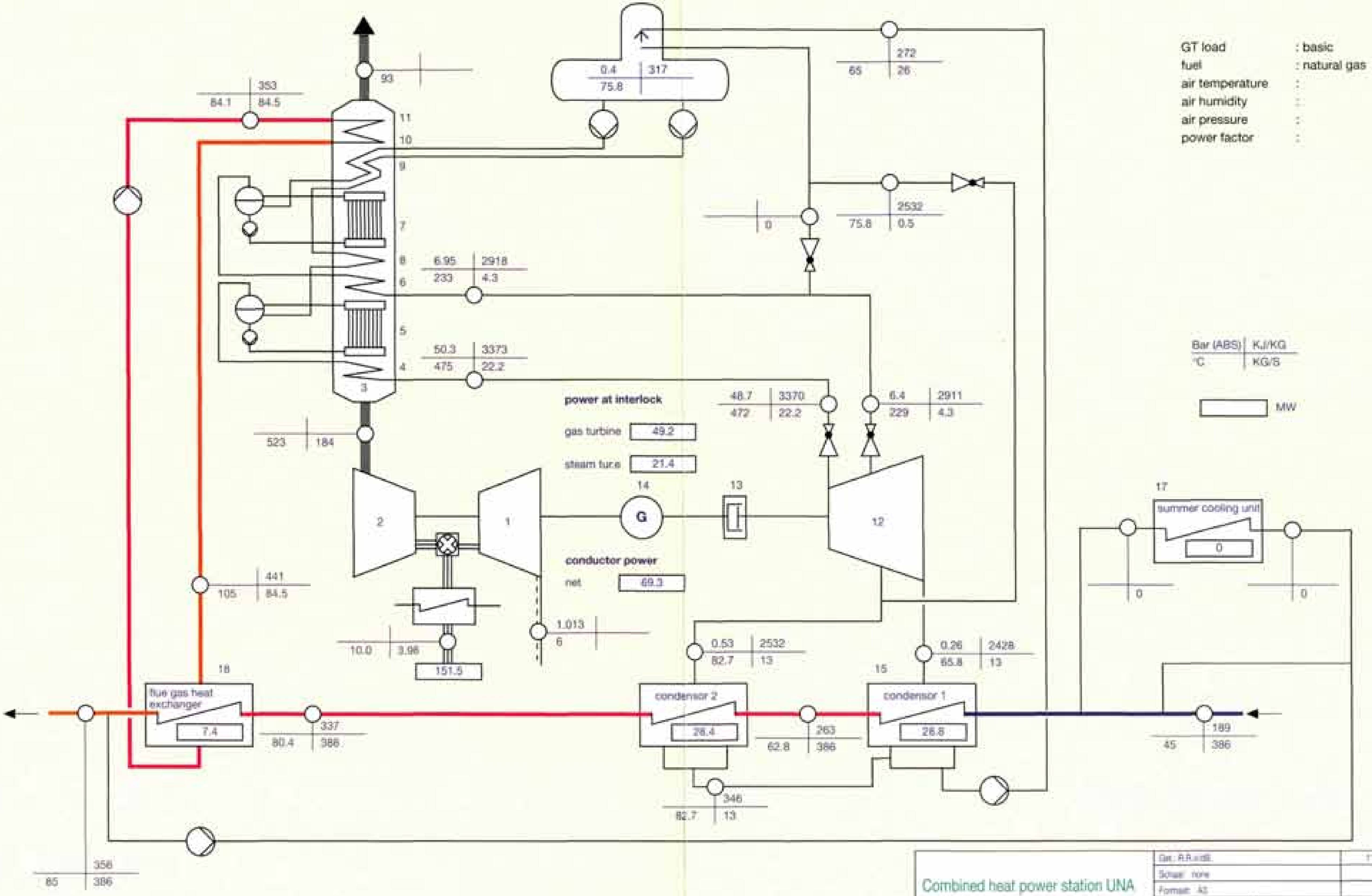
A flow circuit diagram is reproduced on page 19. The gas-turbine consists of a compressor (1), a circumferential combustion chamber and a power turbine (2). Compressor and power turbine are mounted on a common shaft. In the compressor intake air is compressed and led to the combustion chamber. There the compressed air is mixed with fuel and subsequently ignited, whereupon combustion takes place under favourable conditions to minimize $NO_x$ production.

The heated gases are led to the power turbine (2) where the gases expand, transferring its energy to the turbine shaft, which shaft is geared to the dual-driven generator (G). The expanded gases are led to a two-stage exhaust boiler (3).

The hot gases from the gas-turbine pass successively a high-pressure super-heater (4),


GT load : basic
fuel : natural gas
air temperature :
air humidity :
air pressure :
power factor :
Bar (ABS) | KJ/KG
°C | KG/S
MW
93
353
84.1
84.5
11
10
9
7
8
6
5
4
3
0.4
317
75.8
272
65
26
0
2532
75.8
0.5
6.95
2918
233
4.3
50.3
3373
475
22.2
523
184
power at interlock
gas turbine
49.2
steam turbine
21.4
48.7
3370
472
22.2
6.4
2911
229
4.3
14
13
G
2
1
12
conductor power
net
69.3
441
105
84.5
10.0
3.98
151.5
1.013
6
0.53
2532
82.7
13
0.26
2428
65.8
13
15
17
summer cooling unit
0
189
45
386
231
55
386
18
flue gas heat exchanger
7.4
337
80.4
386
condensor 2
28.4
263
62.8
386
condensor 1
28.8
231
55
386
346
82.7
13
356
85
386
Combined heat power station UNA
Tek. nr. HTDM 620 158-4
Get. R.R.v.dB.
11-12-92
Schaal: none
Formaat: A3
Ont.
Gez.
Datum
Rev.
District heating department


GT load : basic
fuel : natural gas
air temperature :
air humidity :
air pressure :
power factor :
Bar (ABS) | KJ/KG
°C | KG/S
MW
103
394
93.9 84.5
0.71 378
90.3
336
80.3 26.3
11
10
9
7
8
6
5
4
3
7.1 2918
233 4.5
0
2553
90.3 0.5
50.2 3365
471 22.3
power at interlock
gas turbine 50.8
steam tur.e 20.2
48.6 3362
468 22.3
6.5 2912
229 4.5
519 188
2
1
14
G
13
12
17
summer cooling unit
0
0
0
conductor power
net 69.7
480
114.3 84.5
1.013
0
10
155.7
0.76 2577
92.0 10.1
0.48 2496
80.2 16.1
18
flue gas heat exchanger
7.2
16
condensor 2
22.2
15
condensor 1
35.4
380
90.5 386
322
76.9 386
231
55 386
385
92.0 10.1
398
95 386
Combined heat power station UNA
Get: R.R.v.dB.
11-12-92
Schaal: none
Format: A3
Gez:
Gez:
Datum
Rev.
Tek. nr.: HTDM 620 158-2
District heating department

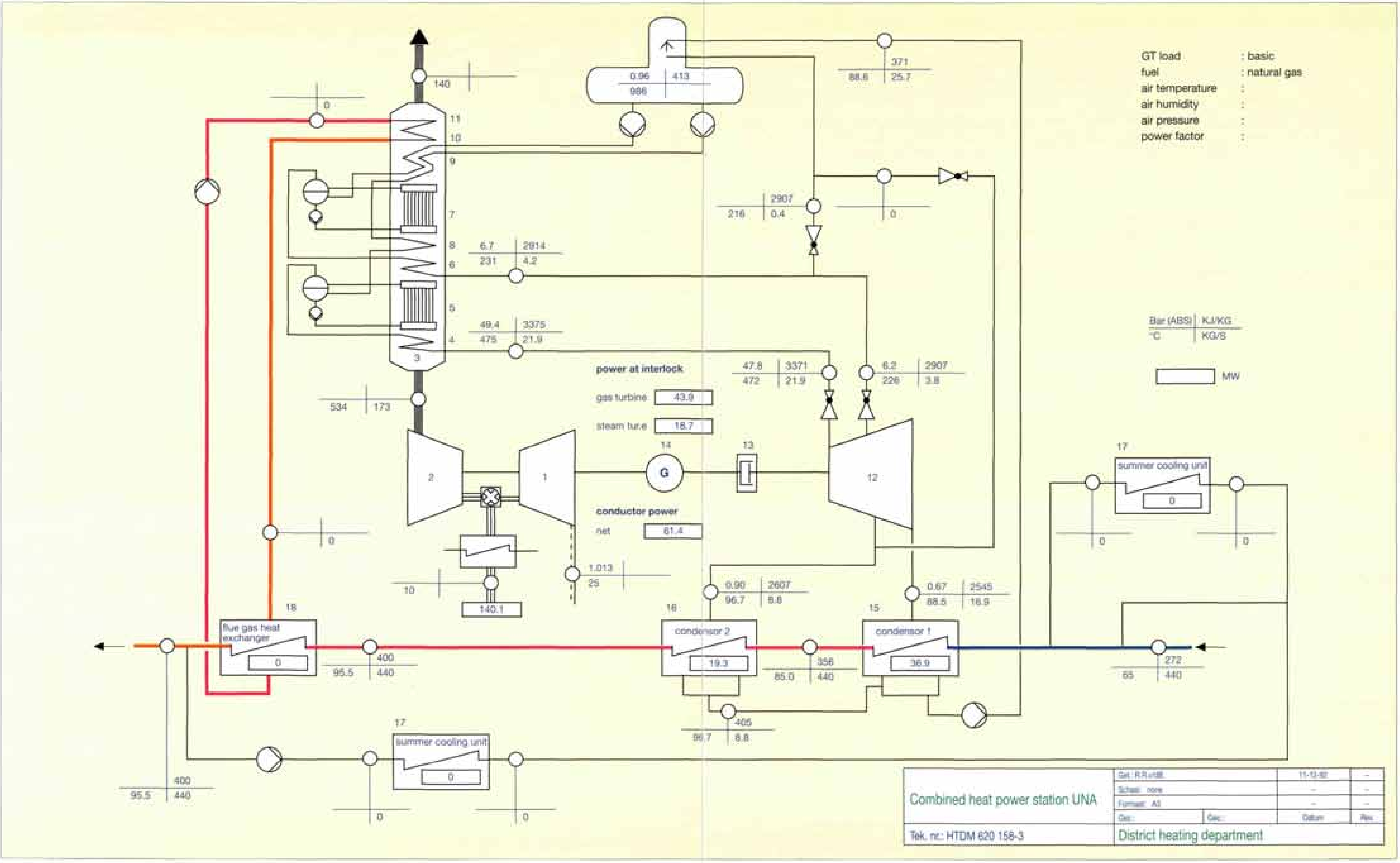


Combined heat power station UNA

| | | | |
|---|---|---|---|
| Get.: A.R.v.d.B. | | 11-12-92 | - |
| Schaal: none | | - | - |
| Formaat: A3 | | - | - |
| Gez.: | Gec.: | Datum | Rev. |

Tek. nr.: HTDM 620 158-1

District heating department


GT load : basic
fuel : natural gas
air temperature :
air humidity :
air pressure :
power factor :
Bar (ABS) | KJ/KG
°C | KG/S
MW
140
0
0.96
413
986
371
88.6
25.7
11
10
9
7
8
6
5
4
3
2907
216
0.4
0
6.7
2914
231
4.2
49.4
3375
475
21.9
power at interlock
gas turbine
43.9
steam tur.e
18.7
47.8
3371
472
21.9
6.2
2907
226
3.8
534
173
14
G
13
2
1
12
conductor power
net
61.4
0
1.013
25
10
140.1
17
summer cooling unit
0
0
0
0.90
2607
96.7
8.8
0.67
2545
88.5
16.9
18
flue gas heat exchanger
0
400
95.5
440
16
condensor 2
19.3
356
85.0
440
15
condensor 1
36.9
272
65
440
405
96.7
8.8
17
summer cooling unit
0
0
0
400
95.5
440
Combined heat power station UNA
Get.: R.R.v.dB.
11-12-92
Schaal: none
Formaat: A1
Gez.:
Gez.:
Datum
Rev.
Tek. nr.: HTDM 620 156-3
District heating department

the HP-evaporator (5), the low-pressure superheater (6), the HP-economizer 2nd stage (8), the LP-evaporator (7), the HP-economizer 1st stage (9) and the LP-economizer(10). Heat is transferred to the water/steam forced circulation circuit, generating superheated steam.
The still moderately hot exhaust gases leaving the LP-economizer are led through an exhaust after-cooler (11) where still useable energy is transferred to the municipal heating system by means of a heat exchanger (18).

Finally, spend exhaust gases are carried off through the smokestack to the atmosphere.

Steam generated in the exhaust-boiler is led to a two-stage steam turbine (12). Within the turbine, superheated steam expands to low pressure saturated steam, transferring energy to the turbine shaft geared to the dual-driven generator (14) by means of an overriding clutch (13). Saturated steam from the two stages of the turbine is condensed in two condensers (15-16), both cooled by heating system water or by the auxiliary cooling system consisting of radiators (17) equipped with ventilators. The latter only in case power must be generated to feed the national grid and no heat can be transferred to the heating system.The condensate is degasified and returned to the boiler feed system.

Table 2, below, shows some typical situations of heating system operation. The situations marked 1 and 3 show wintry conditions with substantial difference in return temperatures (respectively 55 en 45 °C). Situation 2 shows summer conditions.

Flow diagrams and energy balances in relation to the contents of table 2 are reproduced in diagrams on pages 18, 19 and 20. Obviously these conditions are illustrative only and at all times the optimal situation will be adhered to.

It appears that at normal outside temperatures the overall efficiency of the gas turbine hardly varies. Only at extremely high outside temperatures is the overall efficiency as well as the power output substantially reduced. The efficiency of the steam turbine depends to a great extend on the incoming, and, even more so, required outgoing water temperatures of the condensers. In table 2 named "cooling water".

When the entrance temperature of the "cooling water" lies at approximately 45 °C and the exit temperature at approximately 85 °C, the optimal efficiency is obtained as well concerning power generation as heat production. At high output temperatures both sag. In extreme cases the fluegas cooler may no longer be contributing, thus wasting available heat.

*Table 2: Efficiency of district heating in three different situations.*

| **Standard figures** | **case 1**<br>(page 20) | **case 2**<br>(page 21) | **case 3**<br>(page 22) |
|---|---|---|---|
| outside temperature | 0.0 °C | 25.0 °C | 6.0 °C |
| energy content burned natural gas | 155.7 MW | 140.1 MW | 151.5 MW |
| developed power gas turbine | 50.8 MW | 43.9 MW | 49.2 MW |
| efficiency gas turbine | 32.6 % | 31.4 % | 32.5 % |
| steam temperature HP | 468.0 °C | 472.0 °C | 472.0 °C |
| return temperature condensate | 80.3 °C | 88.6 °C | 65.0 °C |
| developed power steam turbine | 20.2 MW | 18.7 MW | 21.4 MW |
| power at generator conductor | 69.7 MW | 61.4 MW | 69.3 MW |
| net electrical efficiency | 44.7 % | 43.8 % | 45.7 % |
| | | | |
| feeding temperature district heating | 55.0 °C | 65.0 °C | 45.0 °C |
| volume district heating water | 386.0 kg/s | 440.0 kg/s | 360.0 kg/s |
| outgoing temperature LP condensor | 76.9 °C | 85.0 °C | 62.8 °C |
| transfered to cooling liquid | 35.4 MW | 36.9 MW | 28.8 MW |
| outgoing temperature HP condensor | 90.5 °C | 95.5 °C | 80.4 °C |
| transfered to cooling liquid | 22.2 MW | 19.3 MW | 28.4 MW |
| heat out of chimney flue | 7.2 MW | 0.0 MW | 7.4 MW |
| outgoing temperature district heating | 95.0 °C | 95.5 °C | 85.0 °C |
| totally transfered to cooling liquid | 64.5 MW | 56.3 MW | 64.5 MW |
| net thermal efficiency | 41.4 % | 40.2 % | 42.6 % |
| | | | |
| **Total efficiency** | **86.1 %** | **84.0 %** | **88.3 %** |

## 2.3 Heat transfer point

The transfer point of heat between the CHPS and the heating system (diagram page 25) is a heat storage tank situated next to the station. Virtually any amount of heat may be transferred to this tank, independent of demand in the heating system. This means that the CHPS may start up, stop and operate separate from the heating system.

The transfer of heat from the CHPS to the heating system takes place in the condensers of the steam turbine and in a water/water heat exchanger taking heat from the fluegases.
The heat exchanger is fitted in a closed circuit incorporating a fluegas cooler situated in the smokestack.
By means of variable speed circulation pumps the, in effect, heated cooling water from the CHPS is delivered to the top of the heat storage tank (page 26). At the same time cold water is drawn from the bottom of the tank.

In turn hot water is drawn from the top of the storage tank by variable speed transport pumps to be fed into the underground heating system. After being cooled down by transferring heat to users, the water flows back to the bottom of the tank.

The system functions properly within a temperature band of 40-65 °C (return flow) to 80-98 °C (supply flow). At a return flow temperature above 55 °C the outlet temperature of the HP-condenser reaches a level whereby only a limited quantity of cooling water can be heated further to a maximum of 98 °C.
Within the band of 40/80 to 55/95 °C the power generating efficiency only varies from 45.9 to 44.7 %.

The heating system, and thus the cooling system of the CHPS, is using demineralised conditioned water. Making-up water for both the water/steam circuit of the CHPS and the heating system is drawn from a storage tank supplied with conditioned water treated in the CHPS.

## 2.4 Operation

The CHPS operation follows demand for heat. This means that demand for heat stipulates how and when the CHPS will be running. In winter the station will be in operation 24 hours per day, at other times less. In the summer season e.g., virtually all heat taken up by the system will only be used to feed the demand for domestic hot water. During this season heat storage capacity will be filled to the brim, whereafter the CHPS will be stopped.

Only when pent-up demand warrants a reasonable running time the CHPS will be started. During the summer season the running pattern is approximately 12 hours running at capacity, followed by 36 hours standstill. The preferable running hours outside the winter season lie between 7 AM and 11 PM following the peak rate for electricity generated.

Because the overall efficiency of the CHPS depends largely on the supply and return temperatures of the heating system, as low as possible temperatures will be adhered to. However, an uninterrupted domestic hot water supply requires a minimum supply temperature of 70 °C in the heating system.

The return temperature depends to a large extend on actual usage, even at times of low demand when circulation is solely created by heat losses in the system.

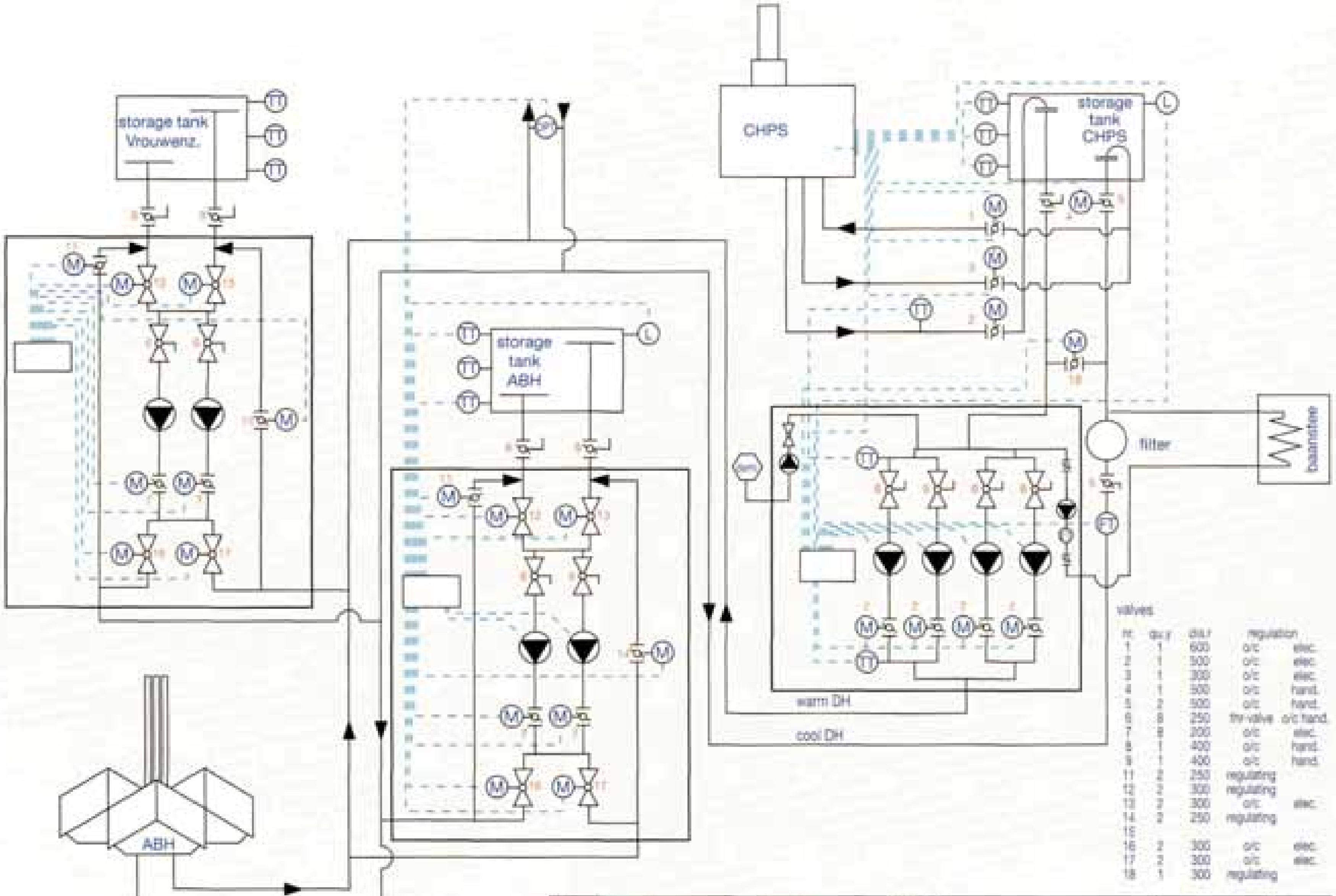
In case return temperatures exceed 45 °C, the return flow is led through the auxiliary cooling system to obtain the most effective lower temperature. This will mean less than full recuperation of heat available but will nevertheless lead to optimal economic conditions because power generation will remain at its full capacity at maximum efficiency.

During the colder seasons the return temperature is no problem because all connections are fitted out with large capacity radiators whereby return temperatures controls are effective.

The introduction of strategically situated heat storage tanks enables local supply of heat at peak demand. Thereby allowing limited pipe diameters. Low resistance in piping made it possible to consume less than 2 kWh per GJ sold.

## 2.5 Development in operating practice

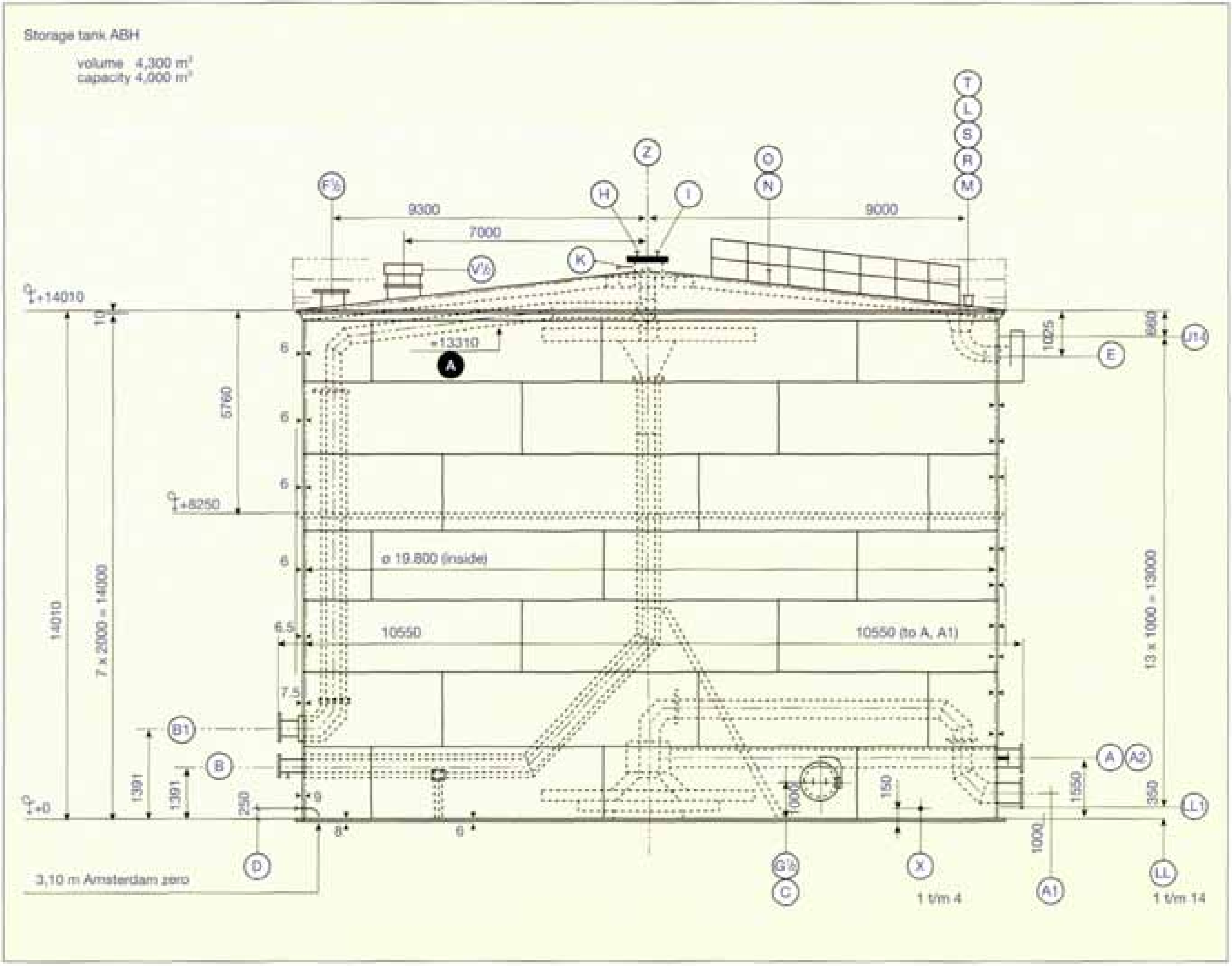
On basis of experience gained, it was concluded that as well the return temperature (45 °C) as the supply temperature (85 °C) could be lowered. This resulted in better performance and lower costs.
This experience offers sufficient scope for new



valves

| nr. | qu.y | dia.r | regulation | |
|---|---|---|---|---|
| 1 | 1 | 600 | o/c | elec. |
| 2 | 1 | 500 | o/c | elec. |
| 3 | 1 | 300 | o/c | elec. |
| 4 | 1 | 500 | o/c | hand. |
| 5 | 2 | 500 | o/c | hand. |
| 6 | 8 | 250 | thr-valve | o/c hand. |
| 7 | 8 | 200 | o/c | elec. |
| 8 | 1 | 400 | o/c | hand. |
| 9 | 1 | 400 | o/c | hand. |
| 11 | 2 | 250 | regulating | |
| 12 | 2 | 300 | regulating | |
| 13 | 2 | 300 | o/c | elec. |
| 14 | 2 | 250 | regulating | |
| 15 | | | | |
| 16 | 2 | 300 | o/c | elec. |
| 17 | 2 | 300 | o/c | elec. |
| 18 | 1 | 300 | regulating | |

| | | | | |
|---|---|---|---|---|
| Combined heat power plant<br>Storage tanks<br>Control storage tanks & interface UNA | Get.: PRJ | | | |
| | Schaal: | | 8-nov-88 | B |
| | Formaat: A3 | | | A |
| | Gez.: | Gez.: | Datum | Rev. |
| Tek. nr.: 17542-3-1005 | District heating department | | | |



Storage tank ABH

volume 4,300 m³
capacity 4,000 m³

heating systems in new to be developed building plans, if and when optimal heat production is made part and parcel of development from the very beginning.

Research is carried out to induce larger buildings, like offices and schools, to introduce floor heating fed by the return from other users. Return temperatures could then be lowered even further, to benefit a still better efficiency of the entire system.

## 2.6 The cost of heat

The CHPS is operated on behalf of the municipality of Purmerend. All capital- and operating costs credited with all compensation received from SEP for fuel, running costs, upkeep and maintenance, and capital costs are billed by UNA.

Capital costs, reduced by a NLG 20 million contribution by SEP, are lower than the corresponding compensation. Costs of running the station, upkeep and maintenance are higher than usual for a full-size power station and the corresponding compensation. Fuel costs are compensated on the basis of a 44 % efficiency in power generation against a fuel mix. The cost of the fuel mix is high during peak hours, virtually the price of natural gas, low during off hours when the mix includes coal firing. Later in time the mix will include the cost of nuclear fuel which will have a detrimental effect. Extra costs during starts are not compensated, nor the reduced number of hours between major service stops and overhauls caused by starting and stopping. In total the cost of heat averages NLG 1.50 per GJ of which the extra fuel demand averages less than NLG 1.– per GJ.

The cost of heat is elaborated with an example in the next paragraph. The figure on page 29 shows the relation between electrical power production, usable heat, waste and the cost of heat.

## 2.7 The STAG combined heat and power plant.

A STAG, STeam And Gas turbine, combined heat and power generating plant meant to serve a district heating system could very well be used by, or in co-operation with, a national or regional power generating authority. A CHPS may be regarded as stand-by capacity, manned throughout he year but only functioning when required. The electric power produced by the CHPS should be reimbursed at a price equal to the cost of power that could be generated elsewhere. Usually these power plants elsewhere are much larger in capacity, with resulting lower investment and running costs per kW.

Existing power plants usually generate at lower efficiency than modern STAG plants.

On page 28 a comparison is made for various situations in which reimbursement may take place, all based upon the costs of a 150 MW power plant and a low temperature heating system in combination with storage tank(s) and cooling capacity.

The latter to be used when the power authority requests full power and demand for heat is low. Also, when choosing for continuous running of the CHPS, more heat may be produced than required whereby the surplus has to be cooled away. Power plants not connected to a heating system cool away all generated heat all the time.

In some cases a subsidy toward a combined heat and power plant will distort the situation as can be read from the first column.

The second column gives the cost/price of heat under the same conditions without a subsidy.

The third column simulates the situation wherein reimbursement takes place on the basis of the best generating plant of the power authority, generating electric power at 55 % efficiency. In combination with a not too modern CHPS the cost of heat will then go up.

The fourth column simulates the case whereby a better CHPS is selected and the heat price will come down again.

The fifth column simulates the situation whereby the CHPS is the most up to date possible and reimbursement takes place upon the basis of the similar best plant within the power generating park of the electricity board.

The sixth column shows the case, not unusual, whereby upgrading of a CHPS, by applying the latest state of the art techniques at time of a major overhaul. This results in more generating power and shows the actual cost of investment of a new, slightly more powerful, plant. Also, the maximum of possible running hours was put in, with time off for service in summer time.

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| cost fuel mix | NLG/GJ |  | 5.00 | 5.00 |  |  |  |  |
| natural gas | NLG/GJ |  | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| capacity E | MWe |  | 68 | 68 | 68 | 68 | 68 | 70 |
| capacity th | MWth |  | - 65 | 65 | 60 | 50 | 41 | 43 |
| fuel consumption | MWth |  | 155 | 155 | 156 | 136 | 124 | 127 |
| hours run | hrs/yr |  | 5,000 | 5,000 | 5,417 | 6,500 | 7,927 | 8,400 |
| number of starts | nr/yr |  | 90 | 90 | 80 | 20 | 10 | 2 |
| E production | MWh |  | 340,000 | 340,000 | 368,333 | 442,000 | 539,024 | 588,000 |
| heat production | MWh |  | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 | 361,200 |
| generating efficiency | % |  | 44 | 44 | 44 | 50 | 56 | 55 |
| overall efficiency | % |  | 86 | 88 | 83 | 87 | 88 | 89 |
|  |  |  |  |  |  |  |  |  |
| capital layout | NLG/kW | 1,479 | 100,572,000 | 100,572,000 | 100,572,000 | 100,572,000 | 100,572,000 | 100,572,000 |
| subsidy | NLG |  | 20,000,000 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| **OPERATING COSTS** | **8 % interest, 20 yrs amortisation** |  |  |  |  |  |  |  |
| capital costs |  |  | 8,206,436 | 10,243,480 | 10,243,480 | 10,243,480 | 10,243,480 | 10,243,480 |
| running cost | NLG/kW | 73 | 4,964,000 | 4,964,000 | 4,964,000 | 4,964,000 | 4,964,000 | 4,964,000 |
| fuel consumption |  |  | 16,766,018 | 16,766,018 | 18,148,582 | 19,109,088 | 21,175,634 | 23,093,738 |
| **total costs** |  |  | **29,936,454** | **31,973,499** | **33,356,062** | **34,316,568** | **36,383,115** | **38,301,219** |
|  |  |  |  |  |  |  |  |  |
| **REIMBURSEMENT** |  |  |  |  |  |  |  |  |
| **basis:** |  |  |  |  |  |  |  |  |
| capital layout | NLG/kW | 1,370 | 93,160,000 | 93,160,000 | 93,160,000 | 93,160,000 | 93,160,000 | 93,160,000 |
| generating efficiency | % |  | 42 | 42 | 55 | 55 | 55 | 55 |
| **actual:** |  |  |  |  |  |  |  |  |
| fuel costs |  |  | 14,571,429 | 14,571,429 | 14,465,456 | 17,358,545 | 21,168,958 | 23,092,364 |
| capital costs |  |  | 9,488,552 | 9,488,552 | 9,488,552 | 9,488,552 | 9,488,552 | 9,488,552 |
| running cost | NLG/kW | 54 | 3,672,000 | 3,672,000 | 3,672,000 | 3,672,000 | 3,672,000 | 3,672,000 |
| **total reimbursement** |  |  | **27,731,980** | **27,731,980** | **27,626,006** | **30,519,097** | **34,329,510** | **36,252,915** |
| **heatprice** | **NLG/GJ** |  | **1.88** | **3.63** | **4.90** | **3.25** | **1.76** | **1.58** |

*Table 3. Cost of heat from a STAG combined heat and power station.*

Much depends upon whether the right size of CHP plant has been selected. When a state of the art CHP plant is used, higher efficiency will generate more power to produce the same quantity of heat.

The first graph on page 29 shows the options of heat and power production. A CHPS with cooling capacity may give out limited quantities of heat when producing power at full load. As the resulting costs of heat depend upon fixed factors, limited quantities will come at a higher price. The lowest possible cost of heat is at full load of both power generation and heat supply. When more heat is required than the CHPS could normally deliver, or when higher system temperatures automatically reduce the power generating capacity, more heat may be produced at reduced power generating efficiency. The cost of heat, taking the reduced reimbursement of power in consideration, will be higher.

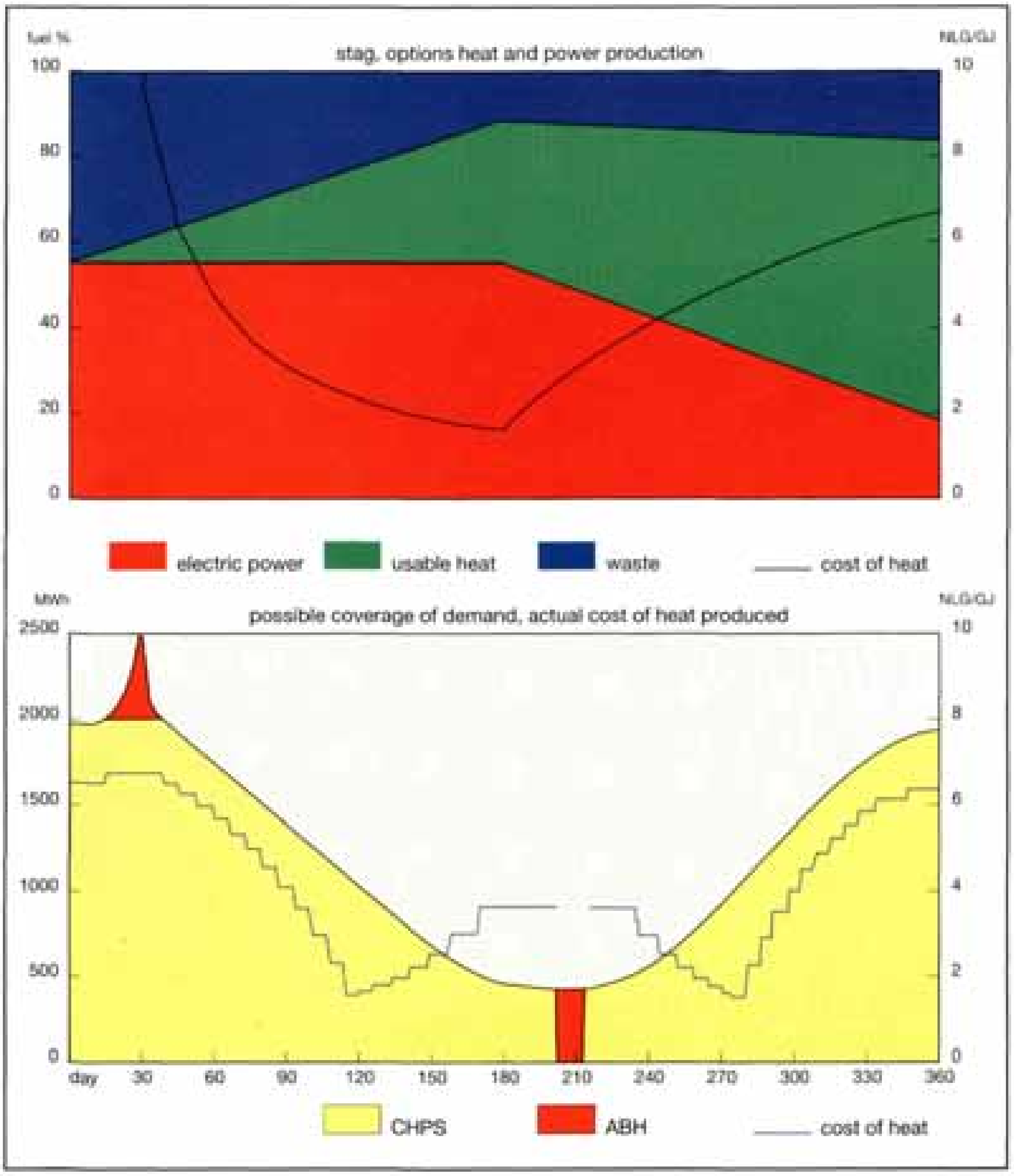
Often, power is generated from various types of fuel. It could be discussed that only the cost of a mix of the various types of fuel should be reimbursed. Other fuel than natural gas will usually mean lower generating efficiency, however.

Demand for heat can be almost fully met by a CHPS selected for the purpose as is shown in the second graph. The actual cost of heat will be determined by the options the CHPS offers. In some situations the cost of heat from a CHPS may come close to the cost of heat that could be obtained otherwise. The yellow supply solids show heat demand covered by the CHPS. The red demand solids show heat demand **not** covered by a CHPS.

Although the actual year-round cost of heat from a CHPS will always be lower than the cost of straight out firing natural gas, optimisation may be called for. The optimum lies in a proper adjustment of demand and generating capacity. Much may be gained by optimisation of heat storage capacity and intermittent operation.

In the case where distribution is separate from major power generation and the distribution company pays a premium for power delivered during peak hours, it could be advantageous to have a CHPS owned and run by the distribution company. Power fed into the national grid should still be reimbursed at standard generating costs of major power plants.

*Table 3. Cost of heat from a STAG combined heat and power station.*



# 3. The hydraulic circuit

### 3.1 Introduction

As explained, the district heating system is fed by a CHPS. The maximum supply temperature is set at 95 °C, the required return temperature at maximal 50 °C. This regime allows a direct operation, where heating system water flows straight through the heating elements for heating and domestic hot water supply.

The location of the CHPS was decided on town planning merits and positioned at the outside of the area served. The ABH is situated in the middle of the area, which is an advantage for supplying additional heat, but a disadvantage for heat supply in case of a break-down of the CHPS. Consequently, further ABH capacity, required when extending the system, will be located next to the CHPS. In regard to heat storage tanks, locations were chosen which facilitated operations, e.g. at the location of the CHPS and the ABH and generally within areas to be served.

The above mentioned attributes are important for the design of a hydraulic circuit. Information is furthermore needed on total heat demand and its development in time. Pipes of larger dimensions may be incorporated in the heat storage capacity of the heating system.

### 3.2 Establishing maximum flow

For several years variations in flow and circumstances connected with these variations were carefully registered (graphs page 31, 32 and 33). It appeared that never more than 5.5 kW heat per housing equivalent was required. The periods during which this maximum is required depend on wind and weather conditions. Peak capacity is not only required in winter, but also for shorter periods of time in spring and fall when outside temperatures are below 5 °C and wind velocity above 4 m/s. Actually, whether conditions only lengthen or shorten the periods over which 5.5 kW/HE is required.

Connection value is theoretically determined by the maximum heat demand per connection (apartment block, one family houses, utility buildings as schools, offices etc.). The actual value is then corrected by taking into consideration only the shell and an inside temperature of 18 °C. This results in a mean connecting value of 10 kW per housing equivalent. The highest mean demand is 5,5 kW/HE, so a simultaneity factor of 55 % may be used in calculations. Because heat is also used to supply domestic hot water, calculations for pipe sizing are based on a simultaneity factor of 65 % when farther away from supply sources. The heating system will eventually serve 30,000 housing equivalents. The maximum heat demand will not exceed 165 MW. The set temperature regime then demands a flow of approximately 3,200 $m^3/h$. In normal situations the CHPS and heat storage tanks supply maximum heat demand. The flow from the CHPS location, including the flow from the storage tank will not exceed 1,850 $m^3/h$, the other two buffers will each supply 350 $m^3/h$. If the CHPS is out of action, the flow from ABH1, including the storage tank will also be 1,850 $m^3/h$.
The graph on page 29 shows operations based on given values. The blue line shows the mean heat demand per day for 20,400 HE (in MWh per day), the yellow bars the heat production of the CHPS in MWh.

In the heating season, December, January and February, the CHPS runs continuously. This prevents unnecessary, energy consuming, starts. If heat supply exceeds demand, the surplus will be cooled down by the auxiliary cooler (17 on page 21).

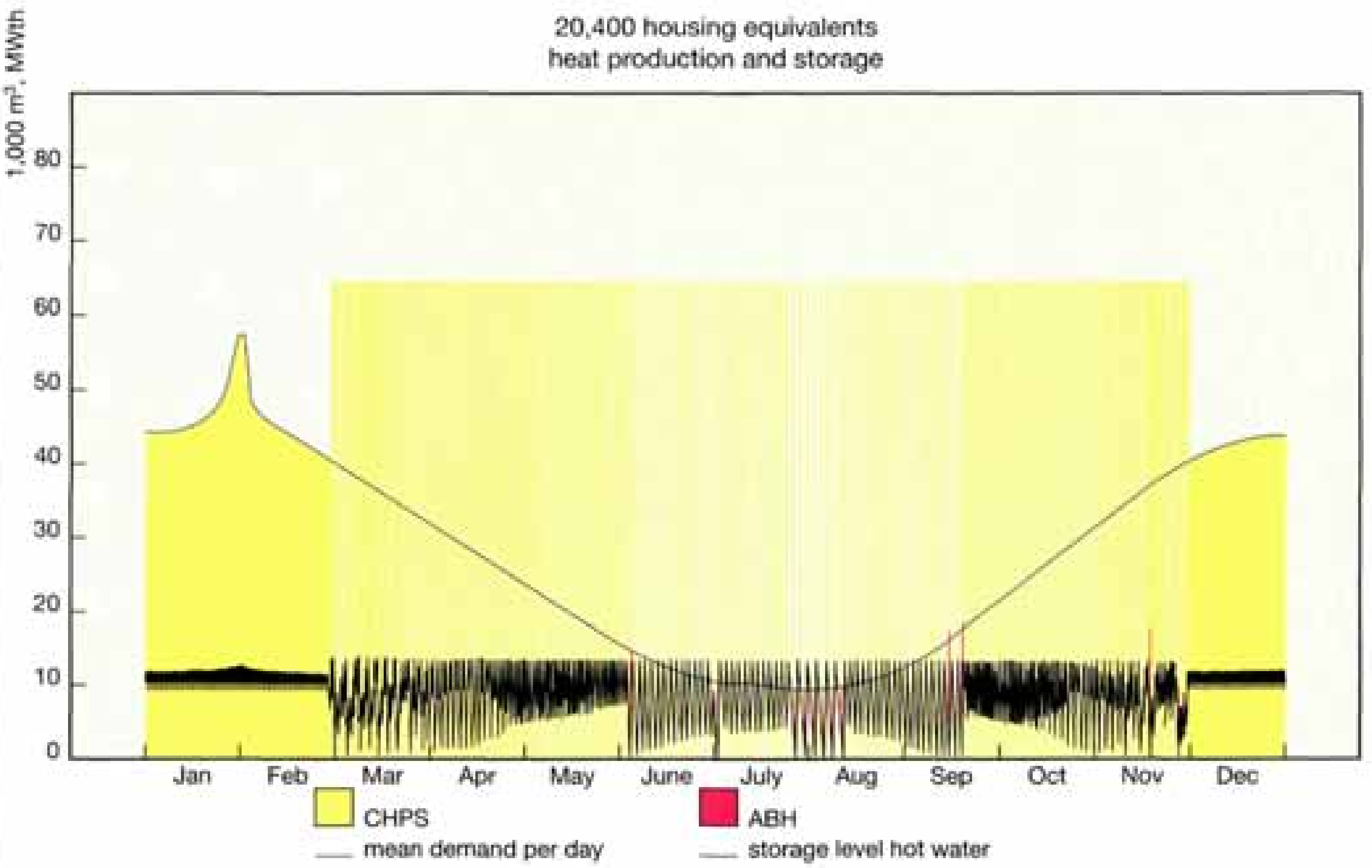
The graphs on pages 31-32 clearly show January/February as the theoretically coldest period. Eventually heat demand will be more than the CHPS can provide, the ABH1 will then supply the remainder. The storage tanks will at all times be prepared.

Outside the heating season the CHPS is operated intermittently at full capacity. Surplus heat is stored in heat storage tanks to postpone the next start as long as possible. The ABH assists if demand cannot be met in carefully planned start and stop periods. This happens only in case weather conditions fall foul of forecast.

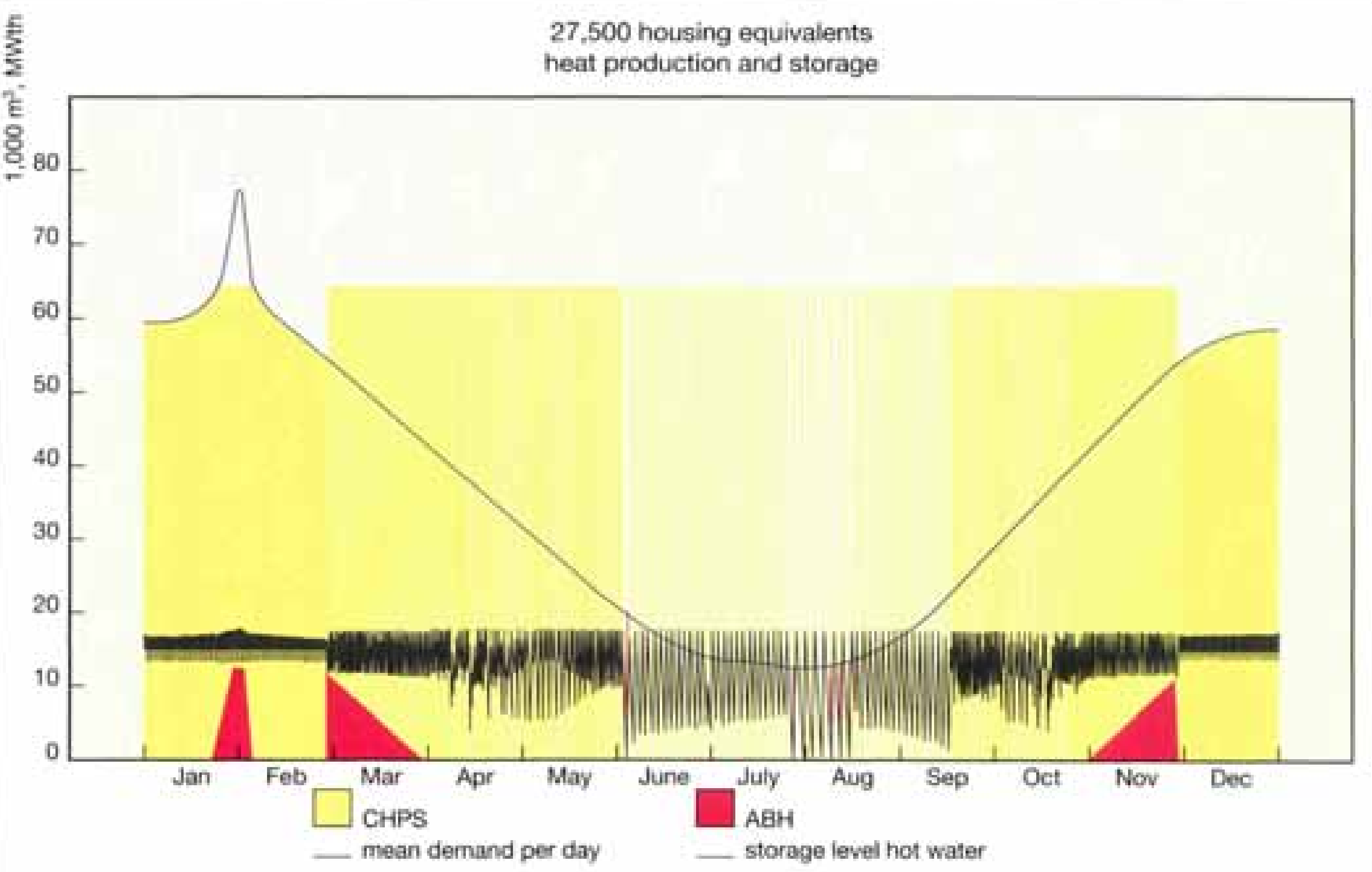
Changes in the level of storage are shown in black fluctuating lines. The level of storage fluctuates little in winter, much more in summer. In summer there is little heat demand and thus the CHPS is started infrequently. The CHPS then runs every second or third day.

### 3.3 Design of pipelines

Velocity of flow is limited. Too high a flow may induce wear and destruction of magnetite

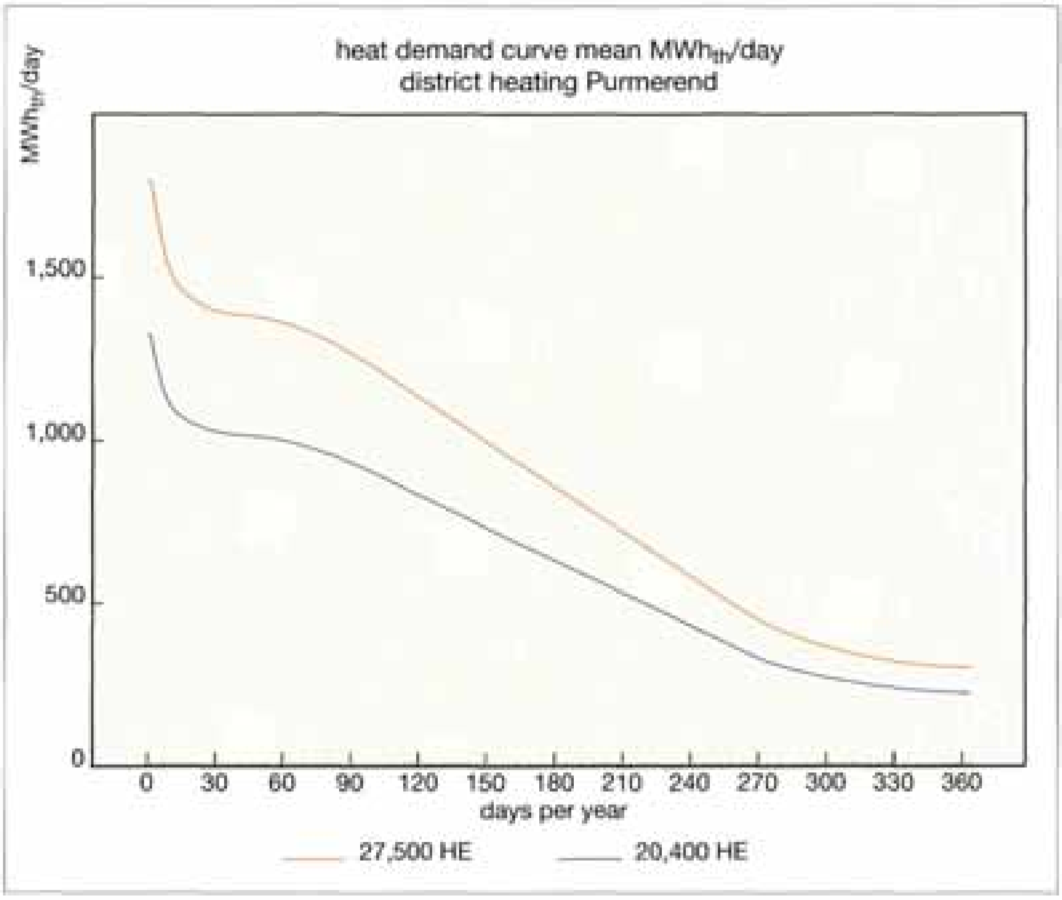


| | | | | |
|---|---|---|---|---|
| connected to district heating | 20,400 | HE | | |
| of which 85% = | 17,340 | houses | | |
| number of degree days | 3210.0 | per year | | |
| mean consumption space heating | 28.0 | GJ/year/HE | | |
| mean consumption hot water | 6.0 | GJ/year/house | | |
| basic load hot water/pipeline losses | 9.4 | $MW_{th}$ | | |
| sum of heat demand | 675,240 | GJ/year | 78 | % |
| heat loss: 0.3 kW/HE | 193,000 | GJ/year | 22 | % |
| total of heat to be produced | 868,240 | GJ/year | 100 | % |
| heat production CHPS | 866,904 | GJ | 218 | starts |
| running hours 64.4 $MW_{th}$ effective | 3,741 | h | 65.0 | $MW_{th}$ max |
| heat production ABH | 1,897 | GJ | 0.2 | % |
| storage capacity | 13,500 | m³ | 35 | °△t |



| | | | | |
|---|---|---|---|---|
| connected to district heating | 27,500 | HE | | |
| of which 85% = | 23,375 | houses | | |
| number of degree days | 3210.0 | per year | | |
| mean consumption space heating | 28.0 | GJ/yearr/HE | | |
| mean consumption hot water | 6.0 | GJ/year/house | | |
| basic load hot water/pipeline losses | 12.7 | $MW_{th}$ | | |
| sum of heat demand | 910,250 | GJ/year | 78 | % |
| heat loss: 0.3 kW/HE | 260,172 | GJ/year | 22 | % |
| total of heat to be produced | 1,170,422 | GJ/year | 100 | % |
| heat production CHPS | 1,133,132 | GJ | 219 | starts |
| running hours 64.4 $MW_{th}$ effective | 4,890 | h | 65.0 | $MW_{th}$ max |
| heat production ABH | 38,082 | GJ | 3.3 | % |
| storage capacity | 18,000 | m$^3$ | 35 | °Δt |

*Figure 13.*
*Heat demand curves 20,400 and 27,500 housing equivalents.*



lining on pipe walls. For the design of transport pipelines the maximum rate of flow (velocity) is set at 2 m/s and or even at 1.5 m/s if sound levels are disturbing. At the design of distribution grids the rate of water flow is limited to 1 m/s.

For calculation purposes it is supposed that the transport grid is fed by the CHPS and storage tanks. In case of emergency and maximum demand the rate of flow in the transport pipelines may temporarily be exceeded.

## 3.4 Friction losses and pipeline sizing of transport pipelines

To arrive at maximum pressure drops, the following should be reckoned with. The storage tanks have a height of 14 m. By connecting these buffers directly to the return transport pipelines, the minimum system pressure will thus be 1.4 bar. In distribution grids, after substations, a pressure difference of approximately 0.4 bar is offered, with a maximum of 0.7 bar. The maximum pressure in the distribution grids is set at 4 bar. Thus the minimum return pressure will be 3.3 bar. The pressure drop in the return pipelines cannot exceed 3.3 minus 1.4 = 1.9 bar.

The supply pipelines have to offer the substations a pressure of at least 4 bar. Add 0.3 bar pressure drop to overcome resistance in filters and control equipment. The sum is 4.3 bar. Pressure drop in supply pipelines is set equal to that in return pipelines. The starting pressure at the point of delivery thus arrives at 4.3 plus 1.9 = 6.2 bar.

To determine dimensions of pipes and pressure drops a computer program is used that takes the following data in consideration:

- demand in kW per substation;
- supply points, formulated as negative consumers;
- simultaneity factor;
- length of pipeline between selected nodes;
- mean water temperature;
- factor to allow for curves, bends, branches and valves;
- standard pipe dimensions;
- highest allowable flow speed;
- pipe wall resistance;
- highest permissable pressure drop;
- starting pressure(s).

The computer program determines on the basis of these data the size of pipe diameters. It is possible to insert the size of certain pipes and have the program calculate the remaining pipe diameters. The program output is a print-out with the remaining pressure in all nodes with flow, pressure drop and velocity between nodes as checkpoints. The computer program also prints calculated pipe lengths of given diameters which may be used to compare options. Heat losses may be computed by inserting the necessary data.

### 3.5 Pipeline-sizing of distribution pipelines

In the last paragraph the premises were given for the pressures in the system. The deduction is that the outgoing pressure after the substations may vary from 4 to 1.7 bar. For lower apartment blocks a higher system pressure and according return pressure is possible.

By feeding the outgoing pressure to the computer program, it is possible to calculate the applicability of all the pipe sizes and check the satisfaction of all parameters. The calculations are limited to one pipeline. The pressure losses are equal in supply and return. The difference in the mean temperature shows just slight deviations. Further the program calculates the necessary pumping capacity to conquer the resistance of the pipeline.

To limit the costs of substations in relation to the distribution nets, it is useful to maximize the connections per substation. Especially when more than one outgoing pipeline per substation is possible, optimization cuts costs. Optimization is possible by incorporating the costs of the substation in the distribution net. Comparing all the costs of different solutions helps to find the optimum number of connections per substation.

Before the transport net can be designed it is important to know all the substations. In the setting of Purmerend it was tried to do so, real developments show deviations of the initial plans.

For the distribution nets it is satisfying to calculate the maximum flow needed to supply the heat for space heating. Only at the end of a pipeline it makes sense to add the hot water supply. In these situations one full connection per ten houses was added after the last branch.

### 3.6 The application of booster pumps

In the district heating network in Purmerend booster pumps are incorporated halfway the heat source and the last consumer. This allows for a reduction of the pressure for the total flow because the booster pumps halfway raise the pressure to the desired level. The capacity of the booster pumps may be calculated with the parameters of the necessary increase of pressure and the flow in the originating node.

Next is an explanation of the last statement. Presuppose a flow of 200 kg/s from the heat source. The ingoing pressure of 1.2 bar is upgraded to an outgoing pressure of 6 bar which results, without booster pumps, in a rest value of 3 bar. The needed pumping power is approximately 122 kW.
In equal pipelines with the use of booster pumps the outgoing pressure from the heat source may be limited to 4.5 bar. This suffices for a rest value of 3 bar for supply on the way before the booster pumps. Half the flow is consumed on the way and the booster pumps only have to upgrade only half the original flow from 3 to 4.5 bar. This equals the pressure drop halfway. The needed pumping power in this case is at the heat source ca. 85 kW, at the booster pumps ca. 20 kW, what sums up to a total of 105 kW.

In almost all cases sufficient starting pressure may be generated to have some rest pressure in the substations. The return pressure after the substation may be too low to conquer the resistance of the pipeline. In that case booster pumps have to be incorporated in the returning pipeline.

A dedicated computer program informs about the necessity of booster pumps with a certain supply pressure and what power is needed. It uses the calculations for the resistance of pipelines and the given pressures at the connection. It is possible to fully optimize the pumping capacity.

# 4. Heat storage

### 4.1 Location of heat storage tanks

Storage tanks will preferably be located in such a way that its pumps may be used as well as pumping stations to fill and empty the tank as booster pump stations to serve the surrounding area. The latter is a matter of providing the correct outgoing pressure.
The effect of storage tanks is at its best when the tanks are located near a proportional share of the heat demand. Geographic limitations by town planning or other obstacles may be corrected by adjusting the outgoing pressure.

### 4.2 Sizing of storage tanks

The capacity and use of a CHPS has great influence on the required storage capacity. Typically, storage capacity depends on the cost of starting and stopping, including the resulting upkeep and maintenance, versus the cost of storage tanks and supporting installations. Also of influence could be a desired running pattern. In the case of Purmerend from 7 AM to 11 PM at any time but the winter months of December, January and February, when continuous operation is permitted and most economic.

In summertime a heat production capacity of 65 MW of the CHPS and a heat demand of 12 MW for heat losses in the transport- and distribution pipelines and provision of domestic hot water, would be amply covered by a storage capacity of 120 MW, (2,500 $m^3$) and two daily runs of 2.25 hours. The following calculation sheds light on other considerations.

Starting the STAG CHPS takes as much as 850 $m^3$ of natural gas, 12 $m^3$ demineralized water and the equivalent of 30 hours running in upkeep and maintenance costs, a total value of approximately NLG 4,500.
The cost of a storage tank is approximately NLG 300 per $m^3$. Operating, upkeep and maintenance and capital costs total close to NLG 30 /$m^3$/year.

Skipping one start every other day during the summer period pays for a storage capacity of 4,500 x 90 / 30 = 13,500 $m^3$. Initially three storage tanks with a total storage capacity of 12,000 $m^3$ were built. These tanks allow for even a two-day stopover if weather permits. In winter only one storage tank would suffice. However, it is just in wintertime that economy of flow can be obtained by filling the tanks with hot water during the night, to be emptied when demand is high and required pressures would be very costly to maintain. Otherwise the system would be fed directly from the CHPS only. Pump savings could be as high as NLG 130,000 annually. When it became clear that the system would eventually feed 30,000 connections, it was decided to built yet another storage tank. A total storage capacity of 16,000 $m^3$ will allow a summer running pattern of a start every third day.

The location of the storage tanks has no influence on the price. De-centrally positioned buffers demand dedicated pumping facilities and control equipment. The costs of a pumping station is calculated at NLG 100,000 per storage tank and is included in the overall cost of NLG 300/$m^3$. By locating two storage tanks at the CHPS the cost can be limited by sharing pumping capacity. When storage capacity is most in demand, during the summer period, the location of storage tanks is not important, friction losses in pipelines will be negligible.

### 4.3 Power required for pumping

Pump capacity was decided upon winter conditions. At peak demand a flow of 600 $m^3/h$ could be required at maximum supply system pressure. Two 90 kW pumps suffice.
Supply of the storage tanks comes from the supply transport pipelines under pressure during off-peak hours. When loading with hot water, the equivalent quantity of low temperature water has to be unloaded to the return transport pipelines by pumping at return system pressure.
When delivering hot water to the supply pipelines, the return will flow freely into the storage tanks.
Power consumption of storage tanks is less than 0.5 kWh/GJ supplied.

# 5. Controlling CHPS, buffers and ABH

## 5.1 Introduction

The hart of the district heating system is the CHPS and the adjacent storage tank which functions as an interface to the district heating system (See scheme at page 25. and figure on page 26). Just like the other storage tanks, the storage tank next to the CHPS is run by DSV *(Dienst Stadsverwarming, District Heating Department)* Purmerend. The CHP operates independent of storage capacity.

DSV submits the following signals to the CHPS:

- Open/closed-signal of the valves in the suction line CHPS (1), in the pressure line CHPS (2), and in the by-pass line to and from the buffer (3);
- A capacity signal, 0-100 MW, 4-20 mA, which shows how much energy is pumped through the pumping station at the CHPS site;
- Signals on a display indicate the heat content and the status of the buffers (supplying, stand by, loading).

Likewise the CHPS submits signals to DSV:

- A flow signal, 0-500 kg/s, 4-20 mA, indicating the flow of water from CHPS to the interface storage tank;
- Suppletion of demineralised water up to 20 $m^3$ per hour with a switch contact.

Personnel of the CHPS has admittance to the pumping station at the buffer to close valves in case of emergency.
The CHPS-DSV contract ensures that the CHPS functions heat demand following: DSV asks CHPS to deliver heat for a certain period of time to the buffer. The required temperature is part of the request. DSV expects that the request is fulfilled. It is possible that the CHPS has to run while there is no heat demand. The cooling down follows the process prescribed in paragraph 2.2. The communication between CHPS and DSV is by telefax.

## 5.2 General control heat sources and storage tanks

If the CHPS produces heat the pumps generate a pressure of 6 bar. If the CHPS is idle the pressure of the transport pumps is lowered to just feed the net from the storage tank. The controls of the buffers elsewhere are autonomous. The central computer of DSV may change the parameters that regulate the storage tank controls to turn the buffers off or on.
The autonomous buffer controls maintain a set pressure. A higher pressure in the net and the storage tank loads, is the net pressure lower, the buffer feeds the net. The auxiliary boilers are controlled the same way: the boilers start up when the pressure in the net falls off and stop again when the pressure exceeds a certain set level.

In the cooperation of CHPS, storage tanks and ABH all kinds of relations are possible. If one storage tank has too little hot water left, the other storage tank delivers more. If the CHPS and the storage tanks do not deliver enough heat, the ABH will start producing heat. If the situation changes again, the ABH and the storage tanks stop supplying heat and the storage tanks start loading heat, if available over and above momentary demand.

By increasing the supply pressure at the CHPS, initiated with a special command, the storage tanks may be forced to load hot water produced by the ABH.

In case of continuous operation of the CHPS in the winter period personnel of CHPS may control the pressure of the outgoing transport pumps. In this way the flow in the transport system may be changed and influences the heat content of the storage tanks.

In the summer season the CHPS delivers water with a high temperature to enlarge the capacity of the storage tanks. The transport net runs at temperatures of 95 °C. The supply temperature in the substations is regulated by mixing with the cooled return flow. This allows for a storage tank capacity of the transport net of ca. 1,500 $m^3$.
When supplying from storage tanks the temperature of the outgoing flow may be regulated by mixing with a part of the return flow.

## 5.3 Controlling CHPS and adjacent storage tank

In the pump room at the CHPS pumps are placed in a cascade connection. All pumps may be switched directly, the first one is controllable.
In winter the total outgoing flow may be handled with three pumps. If the CHPS is active, the flow signal switches to a higher pump pressure (activity level 2).

The regulation of the cascade connection function: see scheme on page 25 and the print of the computer screens at pages 38 - 41.
The first pump starts with a closed down delivery valve (7) which opens, after the start signal and a 10 seconds time delay, in 60 seconds. The delivery pressure is regulated by variable pump speed. From a set minimum the pressure is increased in relation to the flow velocity, following the resistance characteristics of the transport net. As soon as the pump is no longer able to generate the necessary pressure, the next pump, with a set capacity, is automatically switched on with a delay of one minute. This pump is switched directly with a star delta switch. Again the delivery valve (7) opens after a 10 seconds delay in 60 seconds, allowing the pump to supply full power. The delivery valve (7) closes automatically when the pump feeds to much water at the going pressure and the motor power exceeds a certain level. The pressure signal activates another pump if the set pressure is not been reached, or the first, variable speed pump, is steered back when pressure exceeds the set-point.

With a decreasing demand the first pump is steered to its minimum before a directly switched pump is switched off with a delay of one minute. The pressure may be a little too high for at most 2 minutes. Excess pressure is disposed of through a pressure valve to the storage tank.

If the heat content of the storage tank is too low and the CHPS is not producing, the pumping facility is switched off step by step.

Return flows from the distribution net go through a flow meter, a filter and a level control valve (5) to the storage tank. In activity level 2 and a too high temperature of the storage tank content, the mixing valve (18) will open and add return flow till the required temperature is realized. The hand-driven valve (4) and the motor-driven valve (5) are normally open. These valves will be closed in case of repairs within the pumping station. The pumps have hand-driven throughway valves in the suction pipes and electrical-driven butterfly valves in the pressure pipes. The first pump has an extra non-return valve.

The throughway valves in the suction pipes are normally open, The butterfly valves in the pressure pipe are normally closed, or the pump must be operating.

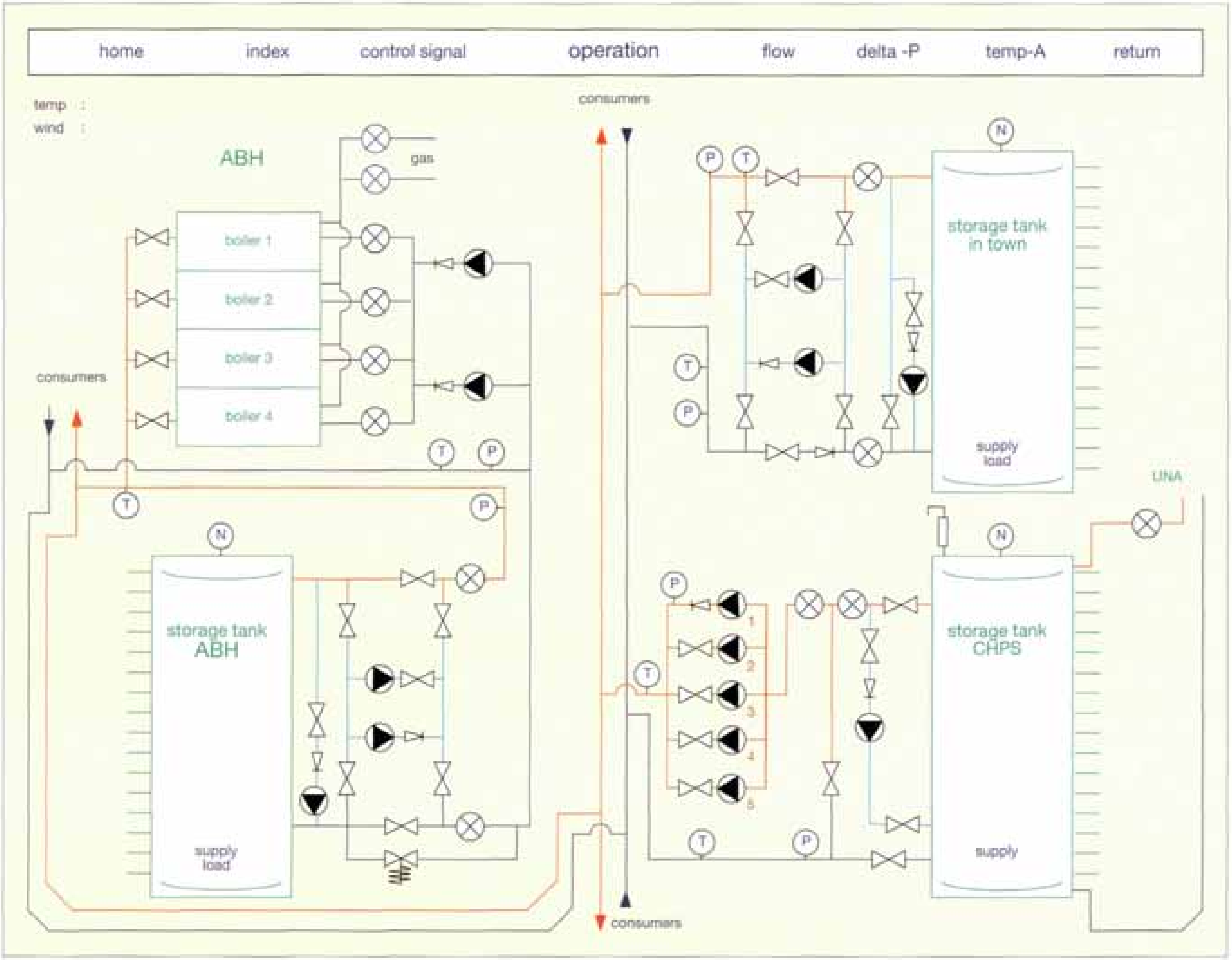
## 5.4 Controlling the ABH and the adjacent storage tank

The pipelines inside and outside the boiler house are designed to operate the ABH as well as the storage tank independently. But they may operate combined. The buffer functions totally independent according to the required pressure in the transport net.
The storage tanks have temperature meters installed at each meter hight. The temperature meters indicate the heat in the storage tank in two ways, in degrees Celsius and as flipping leds on displays. The temperatures may be read on the spot and in the central computer.
The leds light up when the required temperature is reached. The display shows with the 15th and the 16th led whether the storage tank is supplying or loading.

The two top and the two bottom leds indicate in combination whether the tank is filled with water of high or low temperature. Two leds are involved to prevent swinging or repeated switching.

The hand-driven valves (8) and (9) outside the tank (see page 25) permit repair of valves and pipes between storage tank and pumps and are normally opened.
For operating the storage tank two pumps are installed, a controllable pump and a set pump. The controllable one may be switched as a set pump. The pumps have, normally opened, hand-driven throughway valves (6) in the suction pipes. The controlled pump has a nonreturn valve in the pressure pipe. The set pump has a controllable, normally closed, butterfly valve (7) in the pressure pipe.

The principle functions as follows. With a buffer filled, or partially filled, with hot water all valves except (8), (9) and (6) are closed. The pressure in the transport line is measured. Is the pressure too low and is there sufficient hot water inside the tank, the valves (11), (13), and (17) open. The variable pump starts and water flows through the valves (9), (13) and (6). The delivery valve (7) opens slowly to release water to be pumped through valve (17).
The control enhances the pumping power till the set pressure is realized. Or, if the variable pump is on full power, after a 30 seconds time delay, the set pump will be switched on and a balance will be reached by reducing the speed of the variable pump.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ABH
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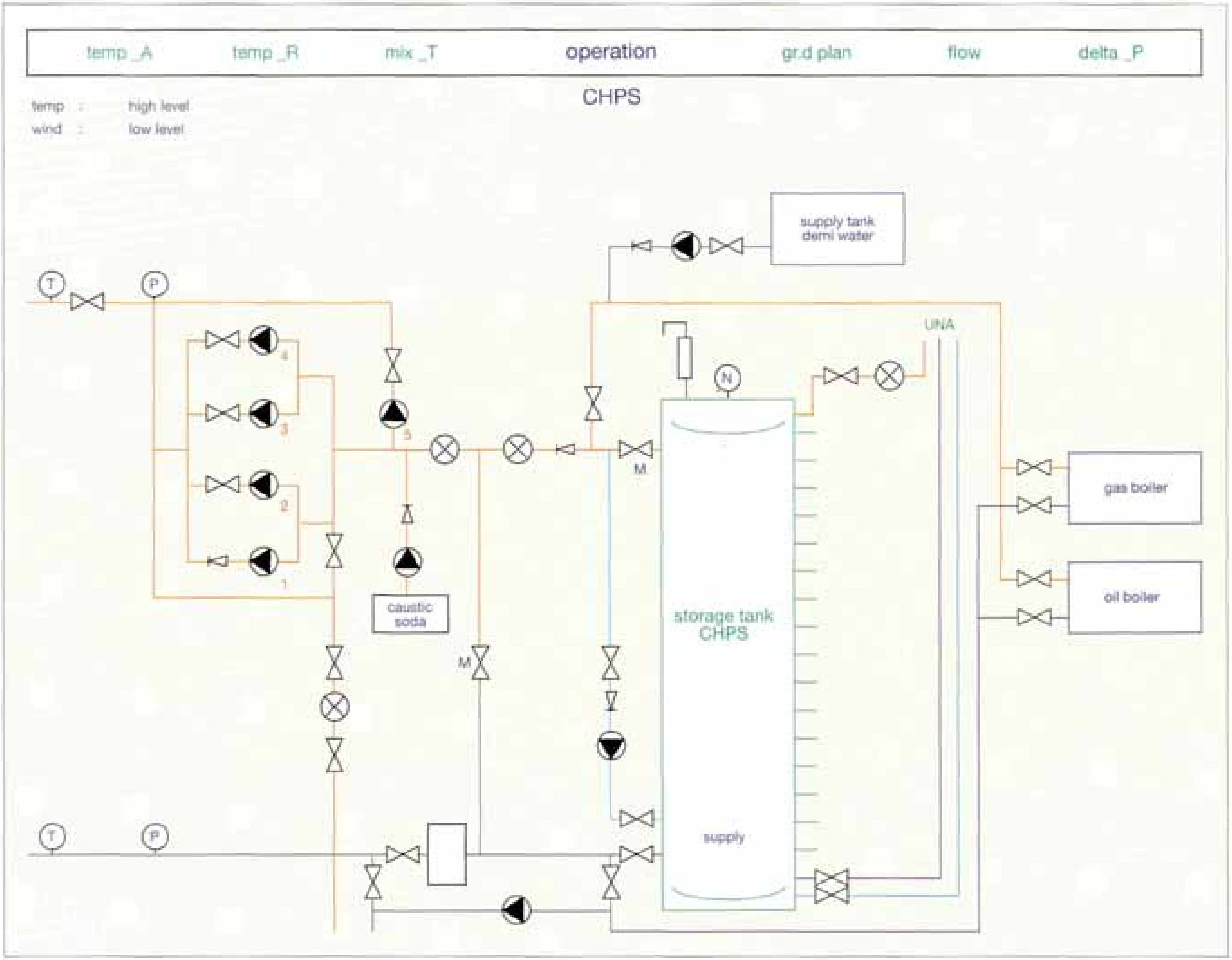
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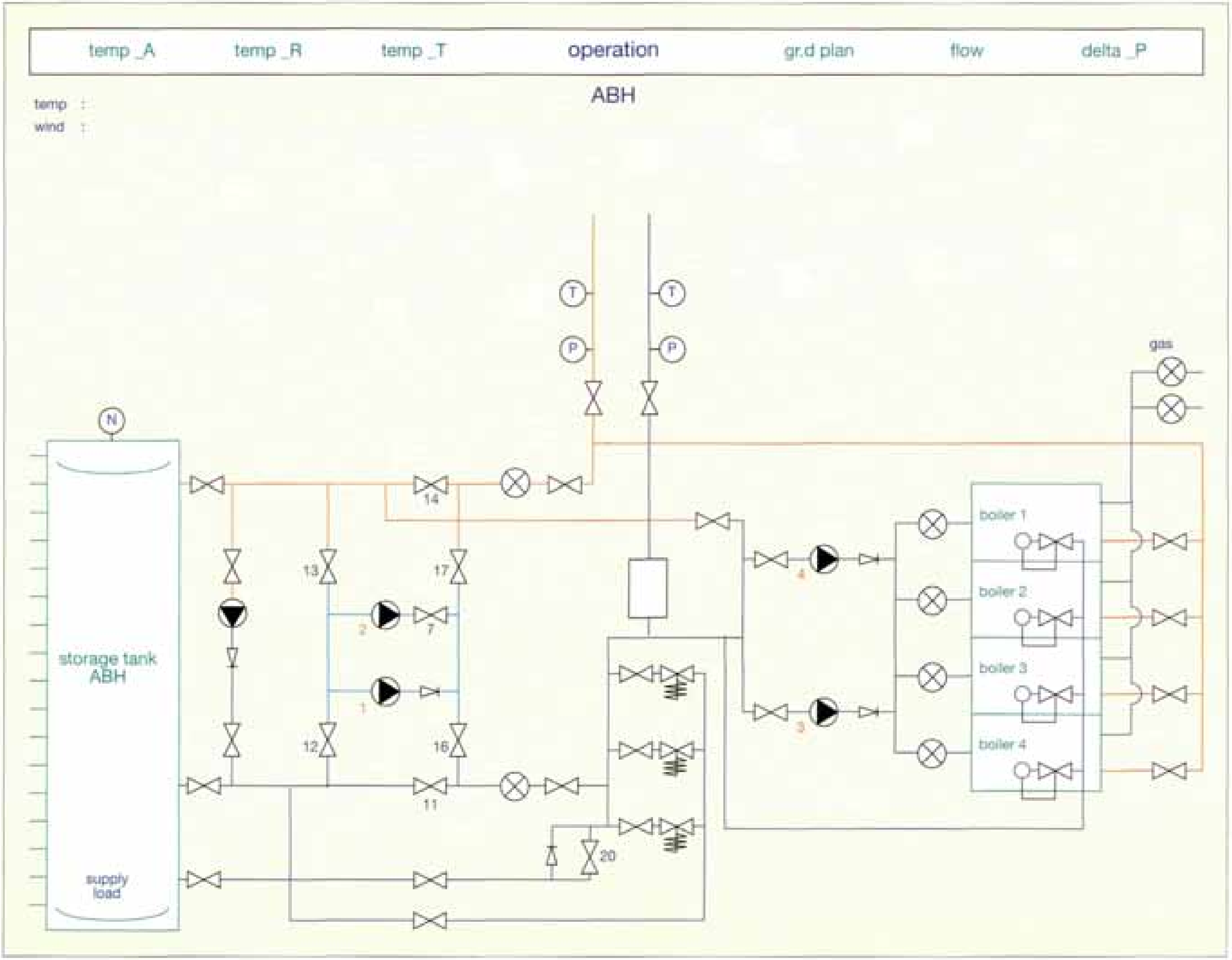
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7
1
4
3
12
16
11
20
boiler 1
boiler 2
boiler 3
boiler 4
storage tank
ABH
supply
load

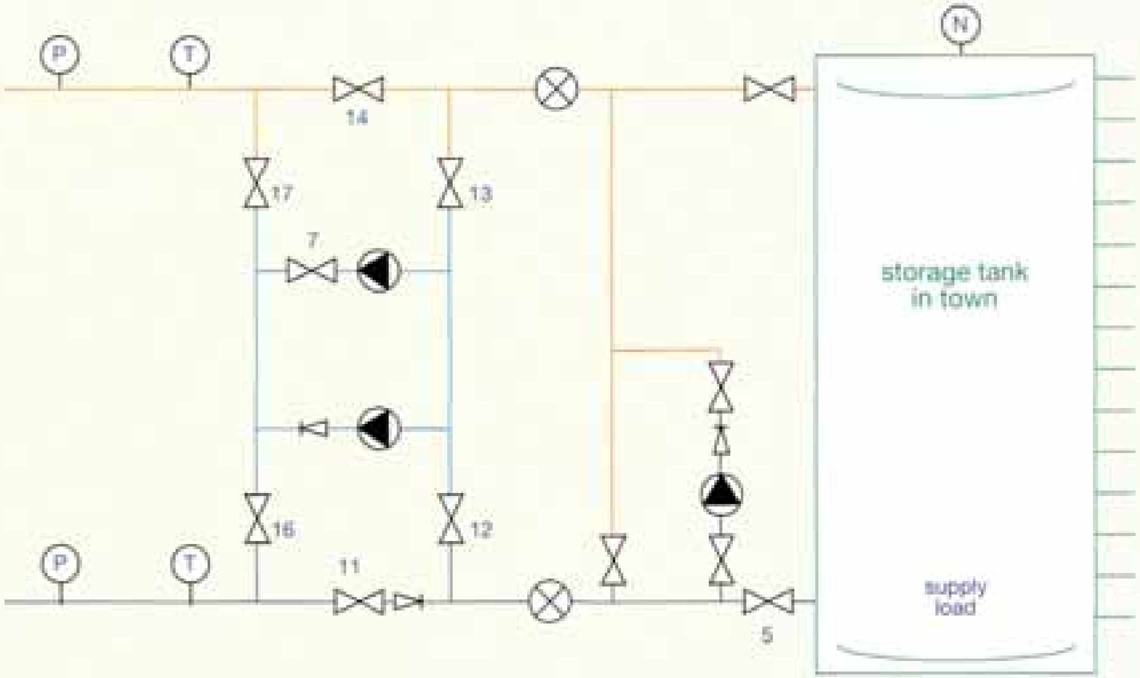
home index operation CHPS ABH return

# TOWN

temp :
wind :

starting temperature right
temperature in ABH2 in town

free to supply
free to load



With the pump(s) in full operation the valves (12) and (13) will be corrected for the set supply temperature. Is the pressure too high than first the variable pump will steer down till the minimum level. Than the set pump will switch off and the variable pump will go for a new balance. Is the level still too high than the variable pump will steer down to the minimum and valve (7) will close with a time delay of one minute. Than almost all valves will close, except (8), (9) and (6) and the pump will stop. The same will happen if the temperature in the top of the tank will become too low.

While the storage tank supplies, the incoming as well as the outgoing flow is measured.
A variation signal will steer valve (11) to create a balance in the flows.
If the pressure in the supply transport pipeline exceeds a certain pressure level, the storage tank will be loaded with hot water. When the excess pressure is steady and the water temperature in the lower levels of the tank is low, the valves (12) and (16) will open. Valve (14) will open to maintain the wanted pressure in the transport lines. The flow into the storage tank is measured and used to steer the outgoing return flow till both balance.
The variable pump starts and water will be pumped away through the valves (8), (12) and (6). The delivery valve (7) will open slowly to allow cool water to be pumped away to the return transport pipeline through valve (16).
As long as the quantity pumped back is smaller than the quantity loaded, the variable pump will be steered up. If the variable pump is at maximum and the variance in quantity continues for longer than a minute, the set pump will switch on and the controllable pump will steer to a balance. This continues till a balance is realized between loading and return flow.

If the ingoing flow is decreasing, because the net pressure drops, the variable pump will steer down. The next step is that the set pump will switch off and the variable pump will seek a new balance. Is the decreasing of pressure constant, the variable pump will fall to its minimum and after a time delay of one minute valve (7) will close. Thereafter all the valves except (8) and (9) will close and the last pump will switch off.
The same will happen when the temperature down in the tank is sufficiently high.

In case the return flow regulation of the storage tanks exceeds the set pressure in the transport net, spring controlled valves will open and let out the excess pressure in the storage tanks for expansion or suppletion. Excess pressure in the supply line will be let out to the outside.

### 5.5 Other storage tanks

The other storage tanks are constructed and controlled in the same way as the storage tank at the ABH. An exception is made for the regulation of the overflow for expansion and suppletion.

### 5.6 Controlling auxiliary boilers

The boilers in the ABH are kept on temperature by a minimal throughflow of the district heating transport net and are continuously stand-by for cascade operation. If the temperature gets below a set level, the burners start to operate to maintain the set temperature.

If the supply pressure of the transport net gets below a set pressure the boiler pump gets into action. After that the first boiler is activated by opening the throughflow valve. The throughflow volume is measured. If the data indicate a volume more than 140 kg/s then, after a time delay of 5 minutes, another boiler is activated, until all four boilers are in operation.

If the first pump does not generate sufficient flow, the second, also variable, pump gets into action. At lowering demand the second pump will be regulated down and switched off, the first pump will strive to balance and switch off only when the pressure level is above the set value. The stand-by situation is than reset.

When the pumps are set in operation by way of the controlled valve (20) (see computer screen for operations on page 40, operation ABH) than a connection is made with the storage tank at the ABH location for expansion and, by a no return valve, contraction of the water volume in the transport net.

At a decreasing supply of the boiler pumps, after a time delay of 5 minutes, the latest activated boiler will be blocked for throughflow. Thereupon the other boilers will be switched off until there is not any supply left.

## 5.7 Water level control storage tanks.

All topsides of all the storage tanks are principally covered and insulated, but are connected with the open air with an overflow. The tanks are atmospheric. The ingoing and outgoing air, during the movement of the water levels, is ventilated through a water seal to prevent condensation. Experience learned that vapour inside the top of the tank has no or very little corrosive effects.

The storage tanks have as well on the topside as on the bottom side a dish for an equalized heat spread. The free space between the dish and the overflow is very limited. The water level is as constant as possible. One of the four storage tanks, the one at the ABH, is designed as a receiving collector for expansion and contraction of the total volume of water in the district heating net. For this reason there is a 300 $m^3$ space above the dish, that means a height of 100 centimetres to spare above the dish.

The level regulation of the storage tank next to the CHPS is by a control valve (5). This valve is controlled by a signal from a pressure-gauge/signal-amplifier and may let the return water flow to the storage tank flow freely or limited (see parameters in table: measured pressure from 1,320 to 1,350 mbar).

The other storage tanks are kept on level by a flow balance regulation. If the level in the tanks comes below a set level, the pumping controls are influenced. This is done by decreasing the speed range of the return pump when loading and by decreasing the deliverance while supplying. The controlled return valve (11) reacts delayed on the reduction of the outgoing flow.
If the level in the storage tanks is above a set level, the pumping controls are also influenced; when supplying the return valve (11) is limited, while loading the inlet valve (14) is limited.
The balance control is delayed.

## 5.8 Combining heat demand, production, flow and buffering

The graphs on 72 hours of heat demand and supply in summer and in winter for 20,400 and 30,000 housing equivalents (HE) show the advantages of using heat storage tanks in a distribution system (see pages 45 - 51).

The first graph on each page shows the heat demand and the heat consumption for three days in summer or in winter. Heat production is shown by the vertical bars where the bottom is heat production at the CHPS and the top at the ABH.

The second graph shows the flows per location. When for 20,400 HE (page 45) in winter only the storage tank at the CHPS is used, the flow

| **Characteristics of storage tank** | | |
|---|---|---|
| Dimension | 19,800 mm | |
| Area | 307.75 $m^2$ | |
| Hight | 14,000 mm | |
| Contents | 4,308 $m^3$ | |
| Highest point / overflow | +13,996 mm, in practice + | 13,990 mm |
| Upper side inflow source | +13,310 mm, in practice + | 13,360 mm |
| Maximum space | + 686 mm, in practice | 630 mm = 194 $m^3$ |
| | | |
| **Allowable maximum level:** | **at a mean of 50 °C** | **at a mean of 90 °C** |
| Consistency of water | 0.988 | 0.9653 |
| Level | 13,682 mm | 13,990 mm |
| Contents | 4,216 $m^3$ | 4,315 $m^3$ |
| Weight of contents | 4,165 tonnes | 4,165 tonnes |
| Pressure at bottom | 1,350 mbar | 1,350 mbar |
| | | |
| **Allowable minimum level:** | **at a mean of 50 °C** | **at a mean of 90 °C** |
| Consistency of water | 0.988 | 0.9653 |
| Level | 13,360 mm | 13,661 mm |
| Contents | 4,117 $m^3$ | 4,213 $m^3$ |
| Weight of contents | 4,067 tonnes | 4,067 tonnes |
| Pressure at bottom | 1,320 mbar | 1,320 mbar |

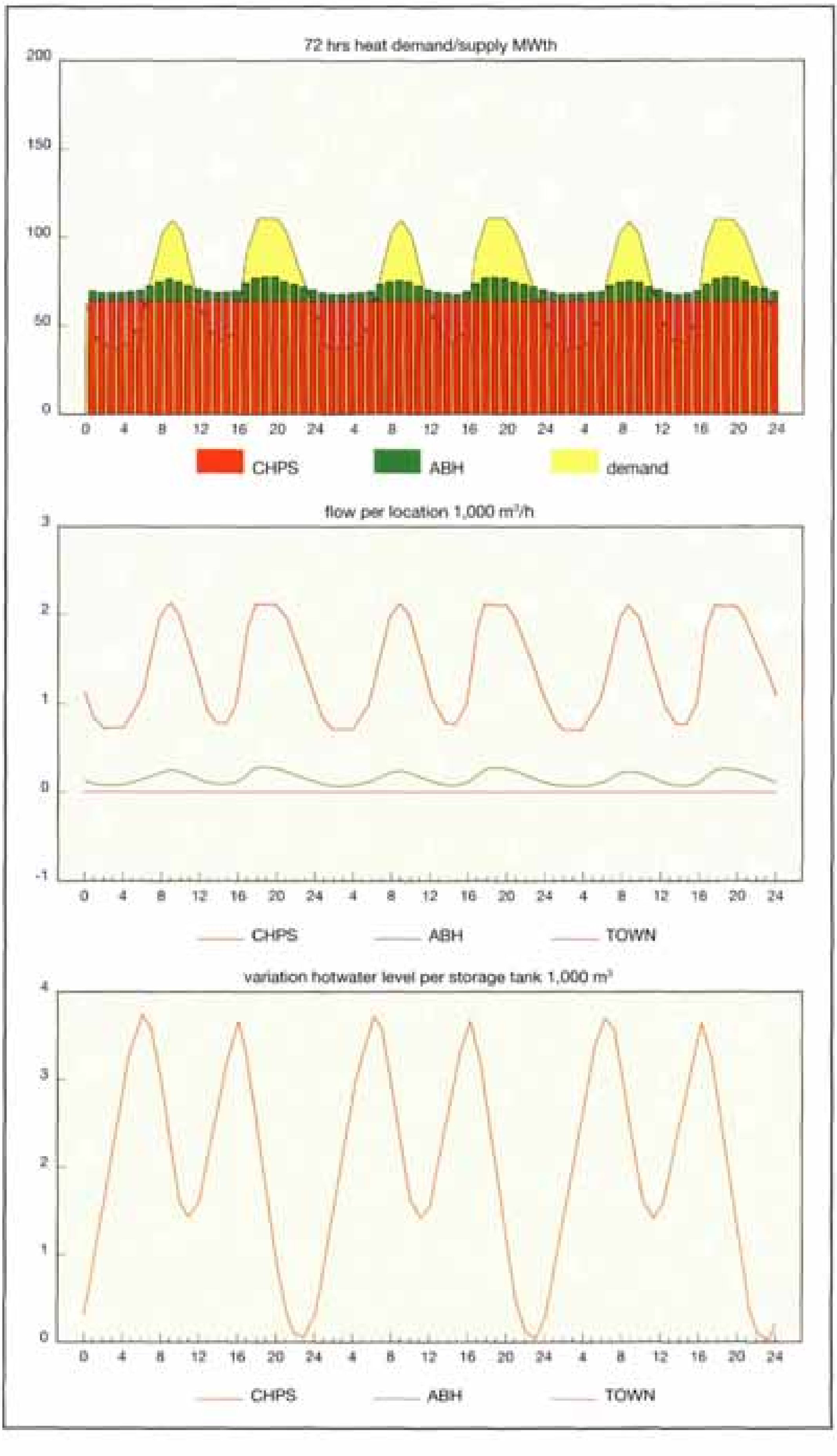
there is high and strongly fluctuating, low and fluctuating at the ABH. If three storage tanks are used (page 46) there is a dampened fluctuation at the CHPS and a fluctuating flow (positive when unloading or supplying, negative when loading) at the pumping stations at the ABH and in town.
In summer with daily heat production (page 47) the flow at the CHPS pumping station resembles heat demand. If the production is concentrated at one day (page 48), the flow is high at the CHPS to feed the storage tanks at ABH and in town and gently fluctuating at all pumping stations while supplying to the grid.

When in winter 30,000 HE have to be supplied with heat, the ABH must produce more. When all flow is at the location where the heat is produced (page 49) the flow is high and strongly fluctuating at the CHPS, less high and fluctuating at the ABH. If the storage tanks are used on other locations as well (page 50), the flow is stable at a high level at the CHPS, high and strongly fluctuating at the ABH, and modestly fluctuating for loading and unloading in town. In summer with heat production concentrated on one day (page 51), the flow is high at the CHPS pumping station to feed the storage tanks at ABH and in town and gently fluctuating at all pumping stations while supplying to the grid.

The third graph shows variation in heat content of the storage tanks.
In winter with 20,400 HE and mainly using the storage tank at the CHPS the heat content of that one varies strongly. Loading when heat demand is lowering in the early hours of the day and partly unloading in midday and completely unloading in the evening (page 49). When the other storage tanks are used too, the fluctuation in heat content is considerable, varying with demand, and the variation in the CHPS storage tank modest (page 46).
In summer the heat content of the storage tank at the CHPS location varies strongly by daily production (page 47). When concentrating the production on one day the variation in heat content of all three storage tanks is comparably increasing while loading and decreasing while supplying heat (page 48).

In winter with 30,000 HE the heat content of the one storage tank at the CHPS location fluctuates strongly with the heat demand (page 49). Using more storage tanks the heat content at the CHPS location varies modestly and at the other location it varies with heat demand (page 50). The heat content of the storage tanks in summer fluctuates with production, loading, and consumption, unloading (page 51).

High flows mean high pumping pressures, low flows savings in pump energy.


72 hrs heat demand/supply MWth
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CHPS
ABH
demand
flow per location 1,000 m³/h
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-1
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CHPS
ABH
TOWN
variation hotwater level per storage tank 1,000 m³
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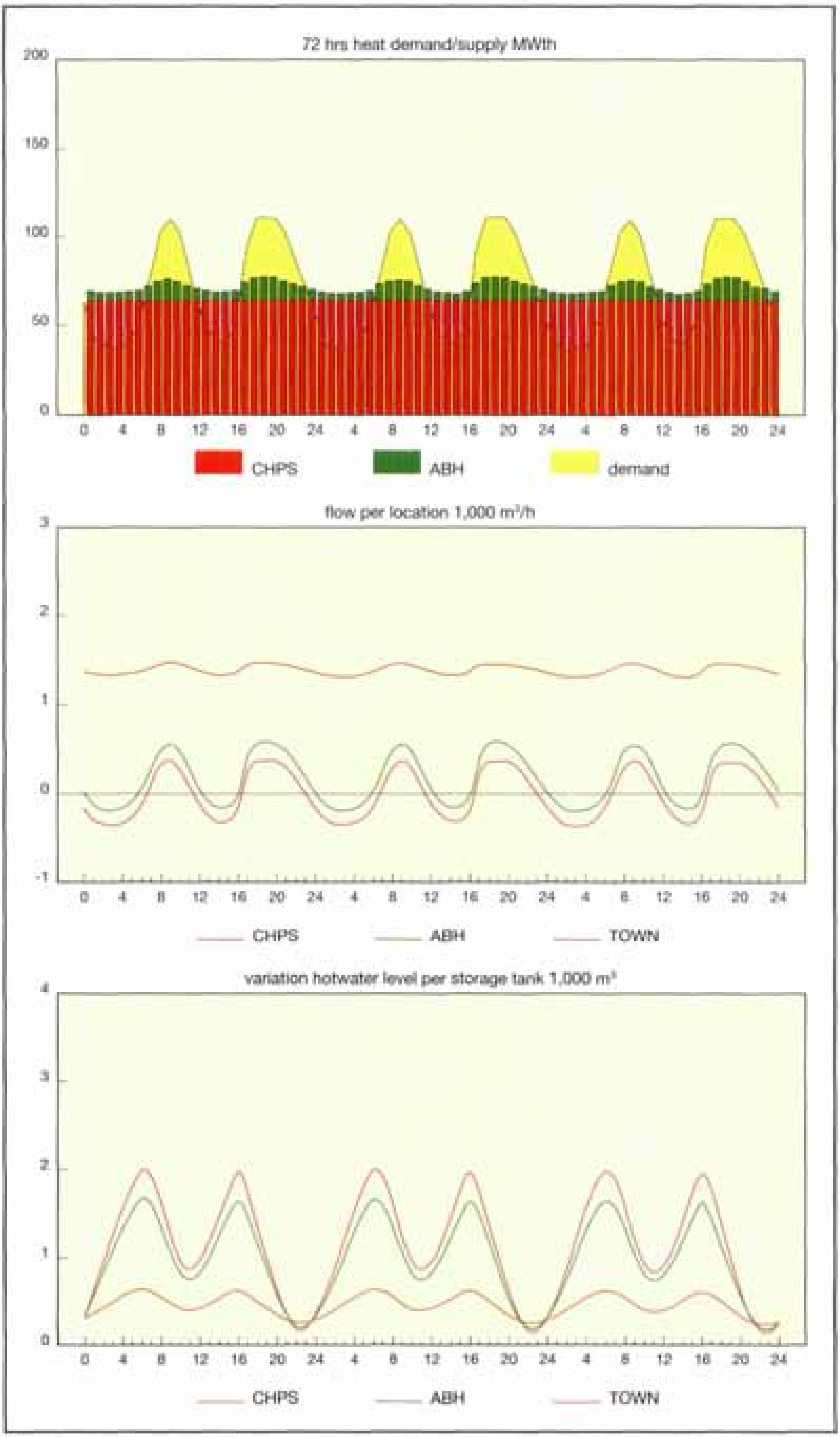
0 4 8 12 16 20 24 4 8 12 16 20 24 4 8 12 16 20 24
CHPS
ABH
TOWN


72 hrs heat demand/supply MWth
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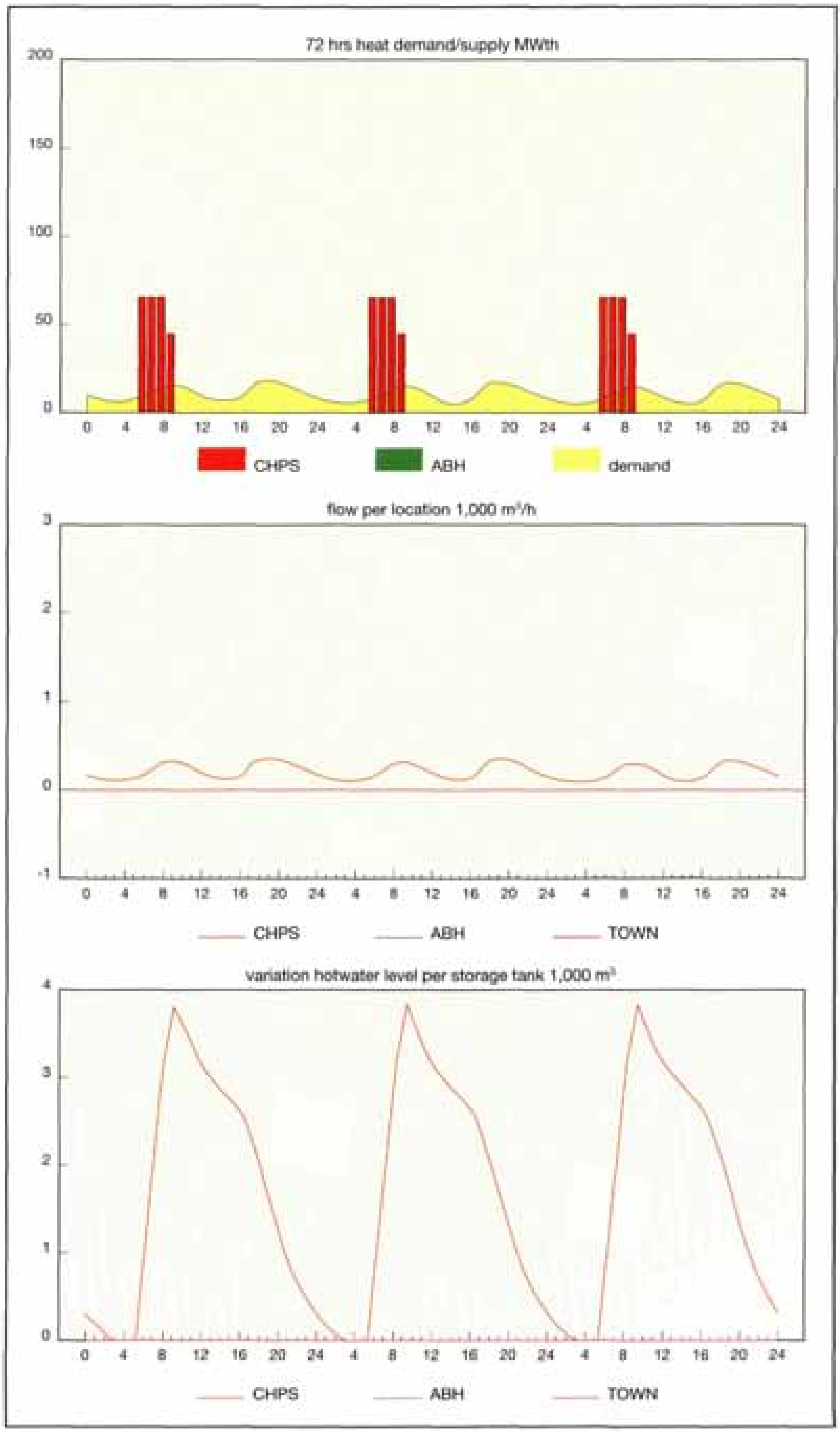
72 hrs heat demand/supply MWth
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variation hotwater level per storage tank 1,000 m³
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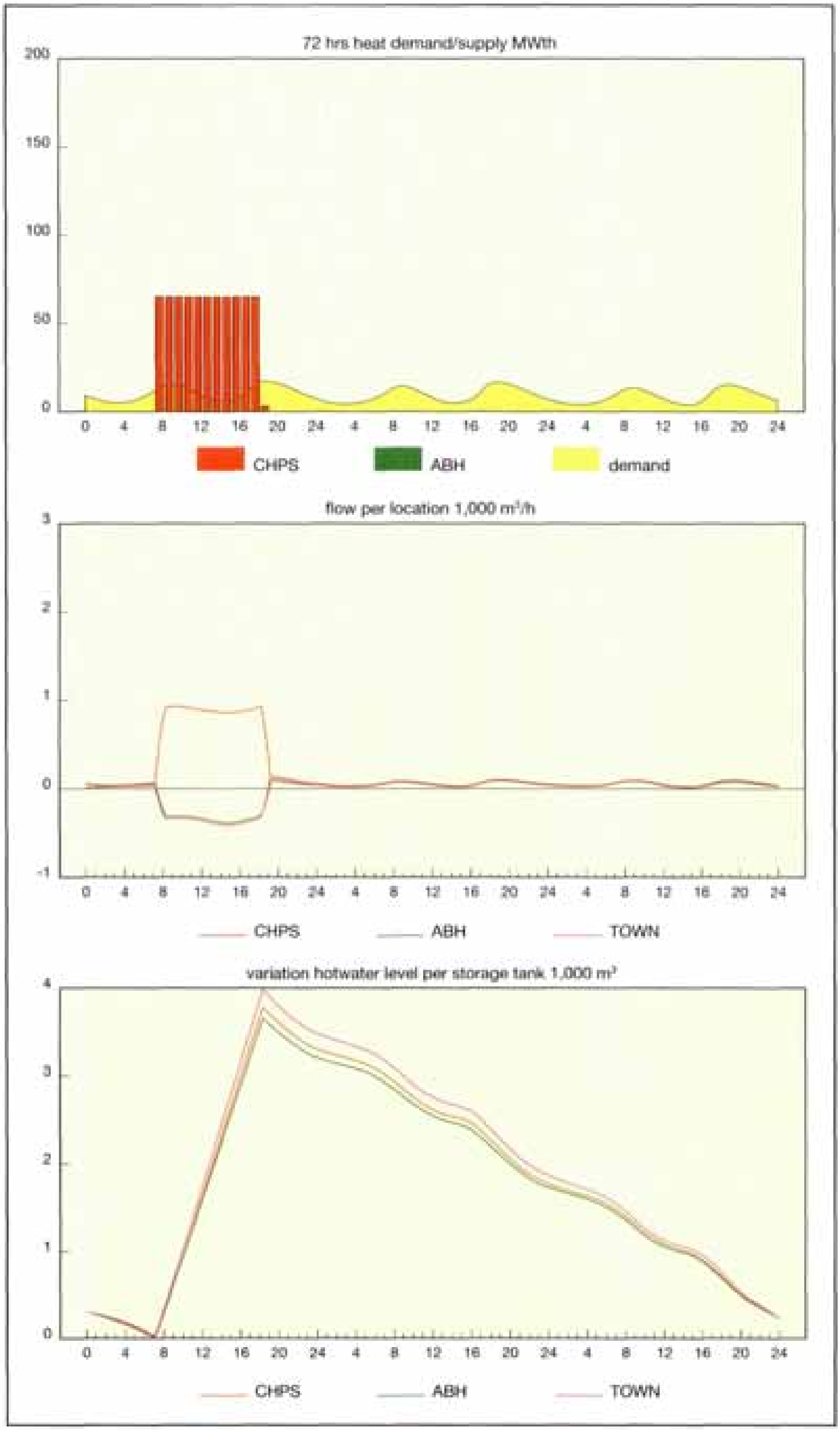
72 hrs heat demand/supply MWth
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demand
flow per location 1,000 m³/h
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variation hotwater level per storage tank 1,000 m³
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CHPS
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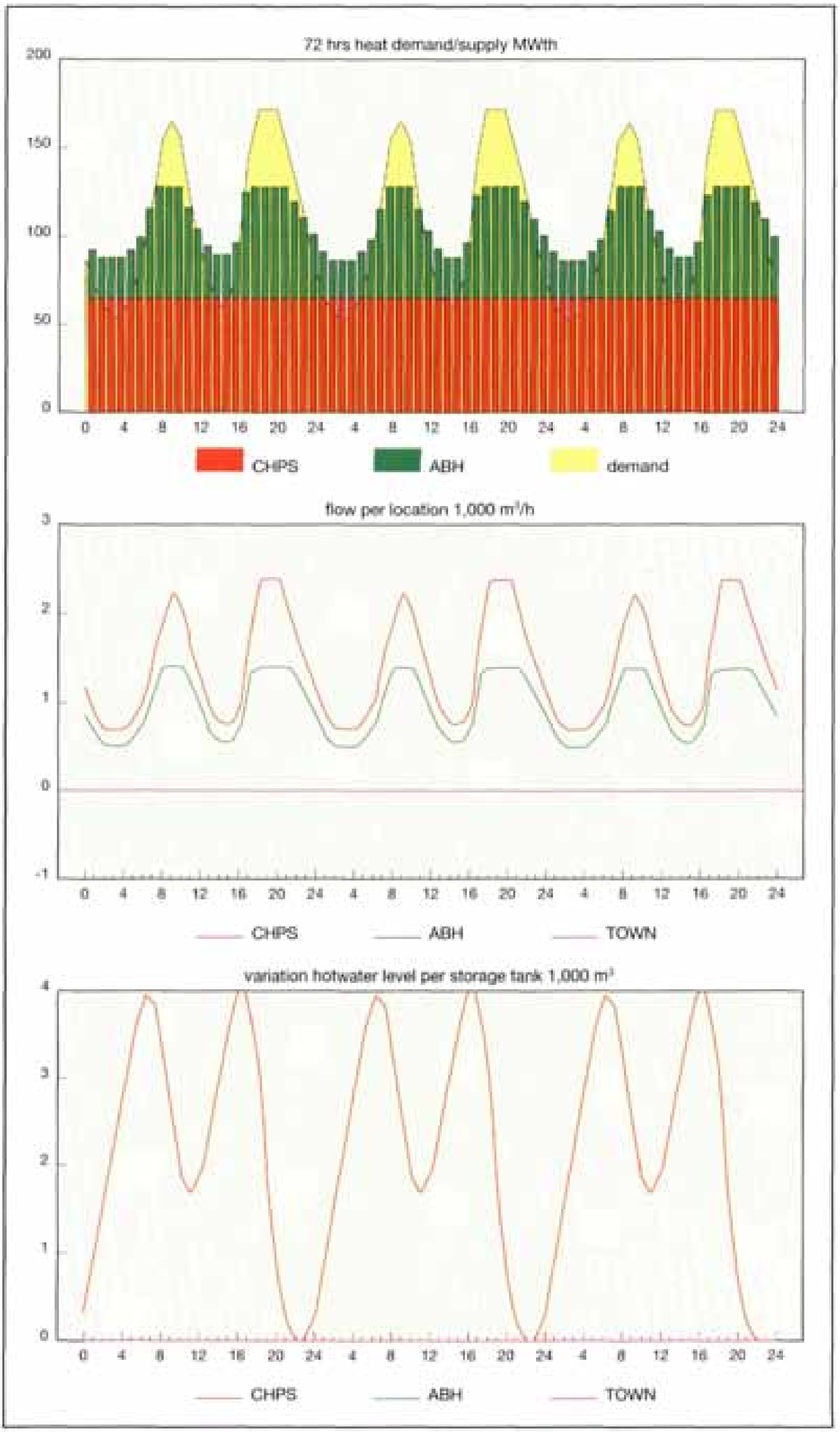
72 hrs heat demand/supply MWth
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demand
flow per location 1,000 m³/h
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CHPS
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TOWN
variation hotwater level per storage tank 1,000 m³
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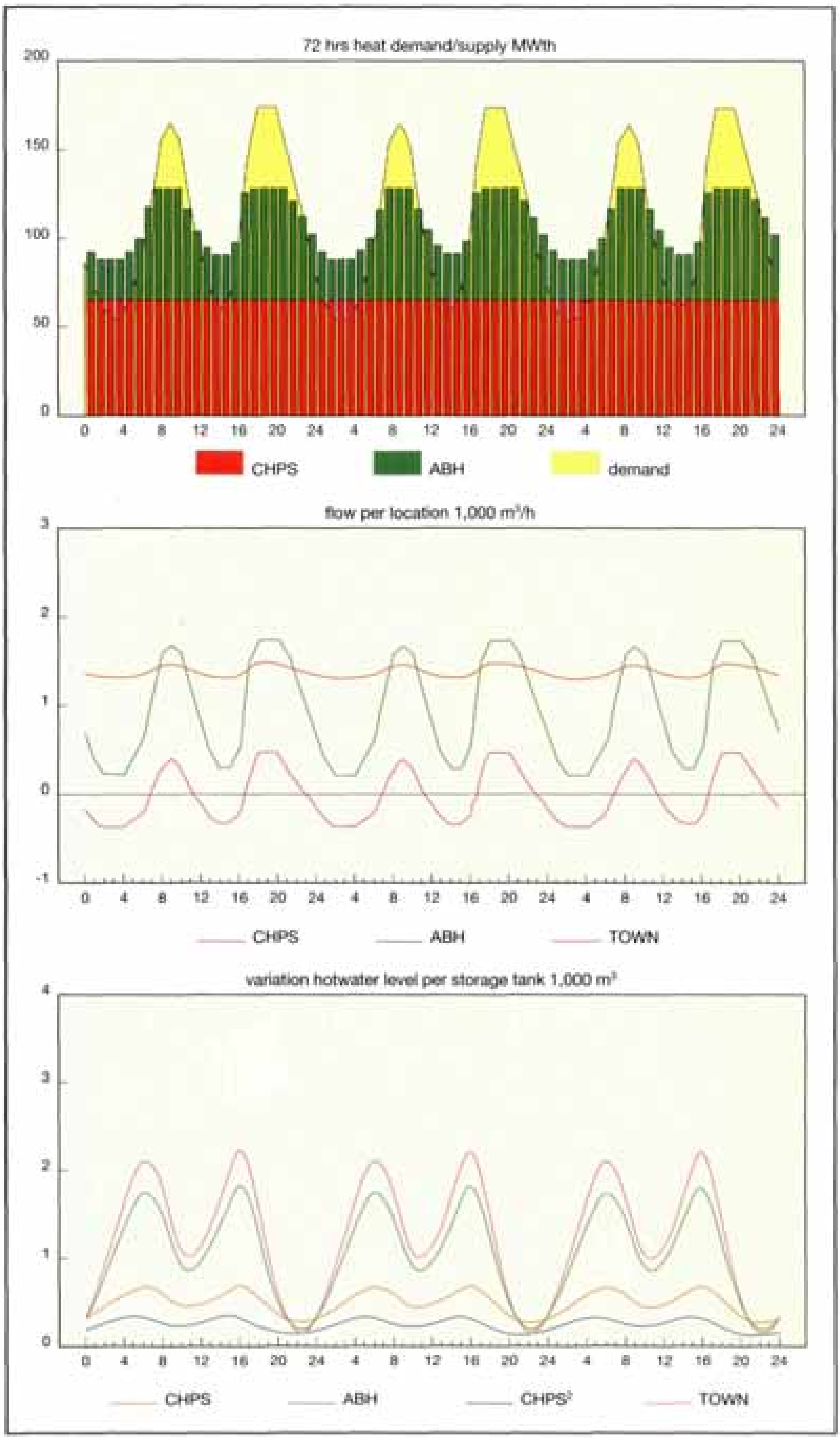
CHPS
ABH
TOWN


72 hrs heat demand/supply MWth
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CHPS
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demand
flow per location 1,000 $m^3$/h
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CHPS
ABH
TOWN
variation hotwater level per storage tank 1,000 $m^3$
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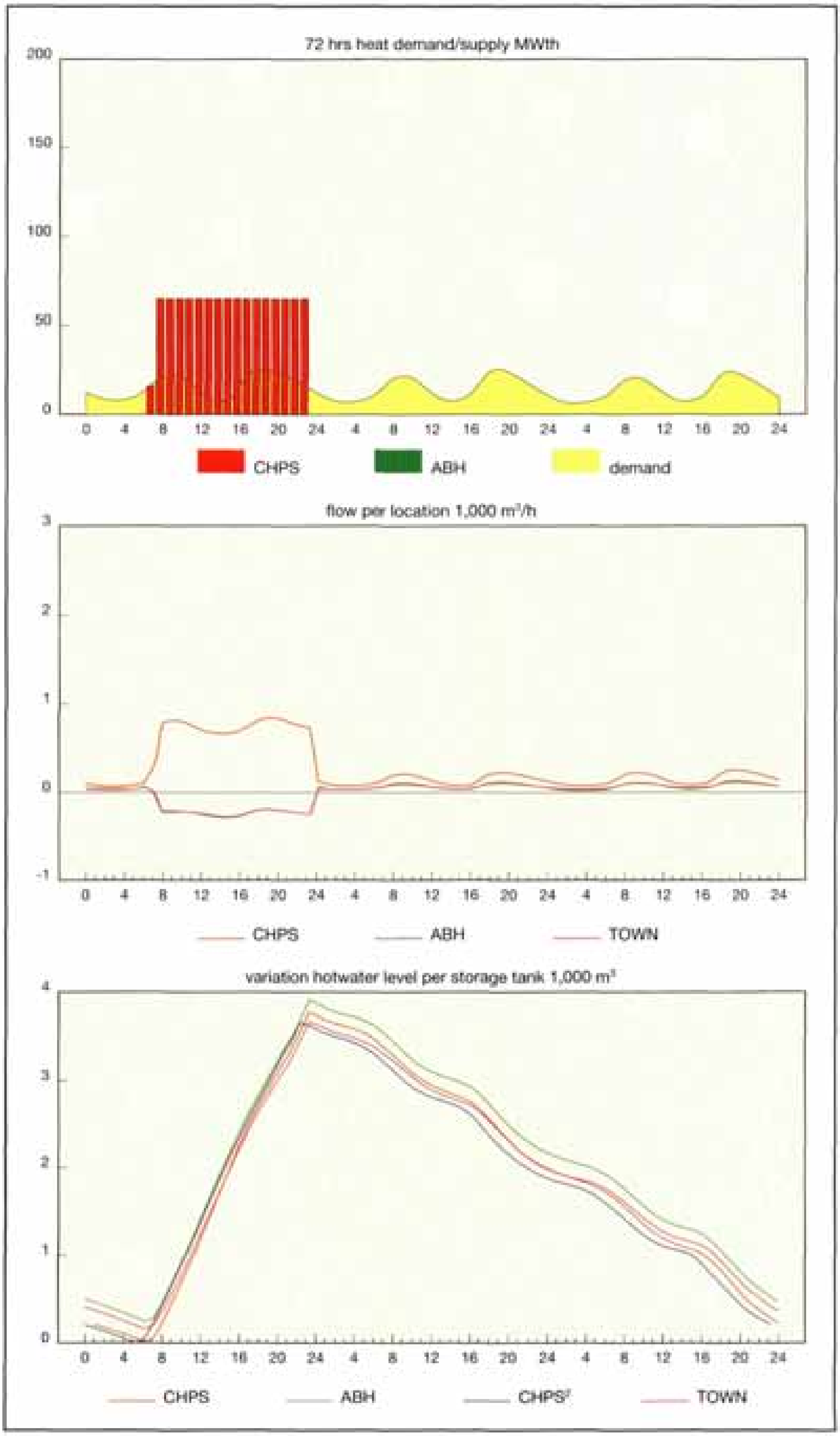
CHPS
ABH
CHPS$^2$
TOWN


72 hrs heat demand/supply MWth
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100
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0 4 8 12 16 20 24 4 8 12 16 20 24 4 8 12 16 20 24
CHPS
ABH
demand
flow per location 1,000 $m^3/h$
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-1
0 4 8 12 16 20 24 4 8 12 16 20 24 4 8 12 16 20 24
CHPS
ABH
TOWN
variation hotwater level per storage tank 1,000 $m^3$
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0 4 8 12 16 20 24 4 8 12 16 20 24 4 8 12 16 20 24
CHPS
ABH
CHPS$^2$
TOWN

# 6. Controlling substations

## 6.1 Control station 2-story-block housing schemes

The control stations or substations for the low-rise blocks in the project Purmerend have as main function the reduction of the supply pressure to maximum 4 bar, the customary pressure in space heating. The controls measure the pressure in the return transport pipeline and reduce the supply pressure to the required pressure difference. The required pressure difference is expressed as a function of the flow. The higher the measured flow, the higher the offered pressure difference to overcome all friction and to have sufficient pressure difference to serve space heating elements and heat exchangers to supply domestic hot water.

Autonomous controls take care of computing the measured flow into a signal to the control valve. The pressure difference going out of a substation varies between 0.7 and 0.3 bar depending on flow.

The control of a substation is autonomous. The controls may be influenced via the central computer to change the parameters of the controls per substation.

Parameters are:
- minimum pressure difference;
- change of set points;
- regulating speed of control valve;
- centralised night correction of supply temperatures.

Every 10 minutes data are collected and registered by the central computer.
These data are:
- supply temperature;
- return temperature;
- mixing temperature;
- incoming pressure;
- supply pressure to the distribution grid after the control valves;
- return pressure from the distribution grid;
- measured pressure difference;
- flow;
- computed pressure difference;
- position of control valve;
- energy passing the station.

During most of the year the flow does not go above the set minimum. In this period a set pressure difference may be maintained. This is done the simplest way, with a mechanical pressure difference valve. If the flow passes a set value the electrically activated control valve will take control. The mechanical control closes the electrical driven control valve as soon as it intends a lower difference in pressure than the mechanical control is set for.

Because each consumer expects sufficient hot water the supply temperature cannot be below 70 °C. In longer supply lines even a higher temperature is needed in the distribution grid. Based on weather-dependent controls a mixing pump may be switched on to mix supply water with return water. This is especially required when the storage tanks are loaded with water hotter than necessary for distribution. The mixing of supply and return water to the set temperature is done by control valve and a fixed displacement pump.

Components of a substation:

*In the main supply line:*
- main valve supply line;
- de-aerator supply line;
- by-pass over the filter for cleaning purposes;
- valve to isolate filter, flow meter and pressure difference control valve for maintenance;
- filter with blow-out valve and pressure meter for indication of fouling;
- flow meter as energy meter;
- a self controlling booster pump when needed;
- branch for mechanical pressure control with a normally opened valve;
- electrically powered pressure difference valve;
- valve for maintenance purposes;
- flow indicator for pressure difference control;
- branch to safeguard for excess pressure;
- main valve distribution line.

*Between supply- and return line:*
- mixing pump between valves and check valve;

*In the return line:*
- main valve in return line distribution net;
- de-aerator in return line;
- self controlling return pump if needed;
- if needed a pressure check valve to maintain system pressure for apartment buildings of medium hight;
- main valve return transport line.

The functioning of the substations low-rise blocks may be read from the scheme on the next pages.

## 6.2 Control station high-rise blocks

From the outset it was stipulated by the town council in 1978 that all apartment buildings would be installed with an individualised installation for controllable space heating and hot water supply. Consumption would be measured individually. To realize the building height of 40 meters automatic variable speed booster pumps were installed. The difference in pressure is set at 0.4 bar. The systems pressure is maintained by a check valve. The controls function autonomously and cannot be influenced. All relevant measured data are reported to the central computer and registered every ten minutes.

Components of a substation for the high-rise blocks:
*In the supply line:*
- main valve supply line;
- de-aerator supply line;
- by-pass for maintenance of filter and controls;
- valve to isolate filter and control set for maintenance;
- filter with blow-out valve and pressure meter for indication of fouling;
- booster pump;
- pressure difference control;
- check valve;
- isolating valve for maintenance;
- branch for by-pass with safety valve;
- main valve supply consumers.

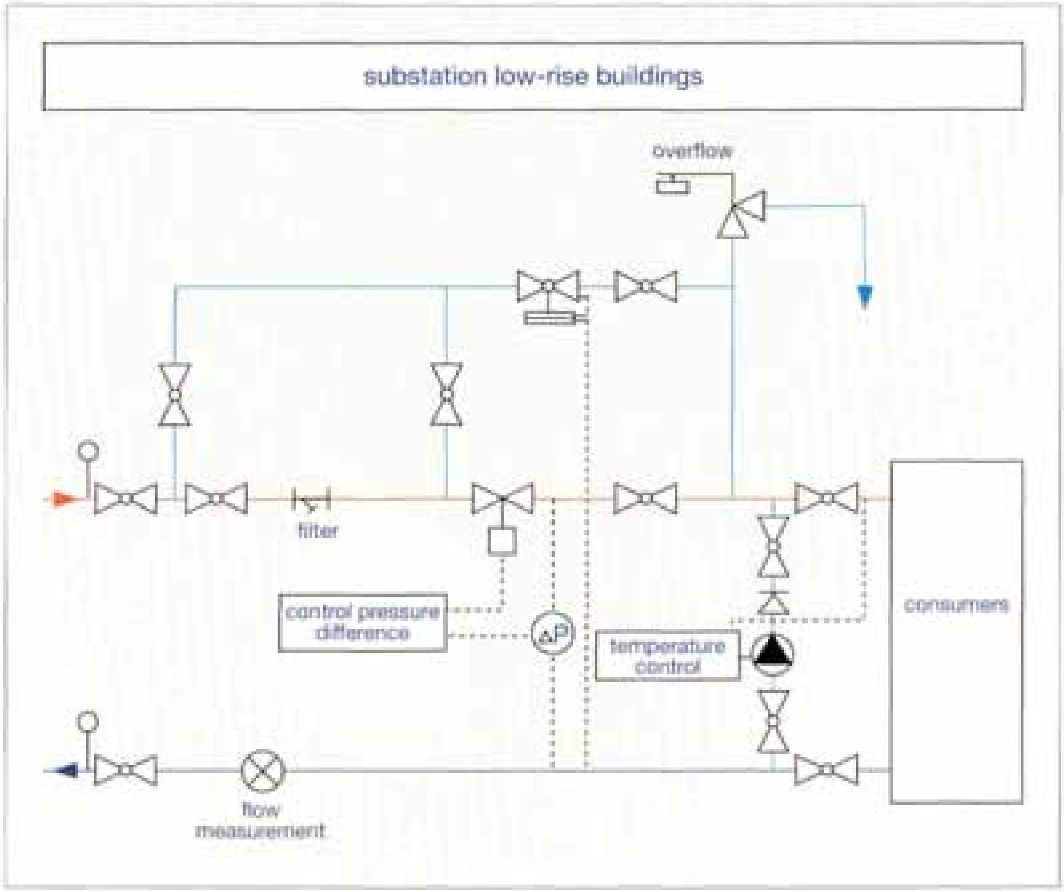
*In the return line:*
- main valve return line consumers;
- de-aerator return line;
- pressure check valve;
- flow meter as energy meter;
- main valve return transport line.

The functioning of the substation for high-rise blocks may be read from the scheme on page ..

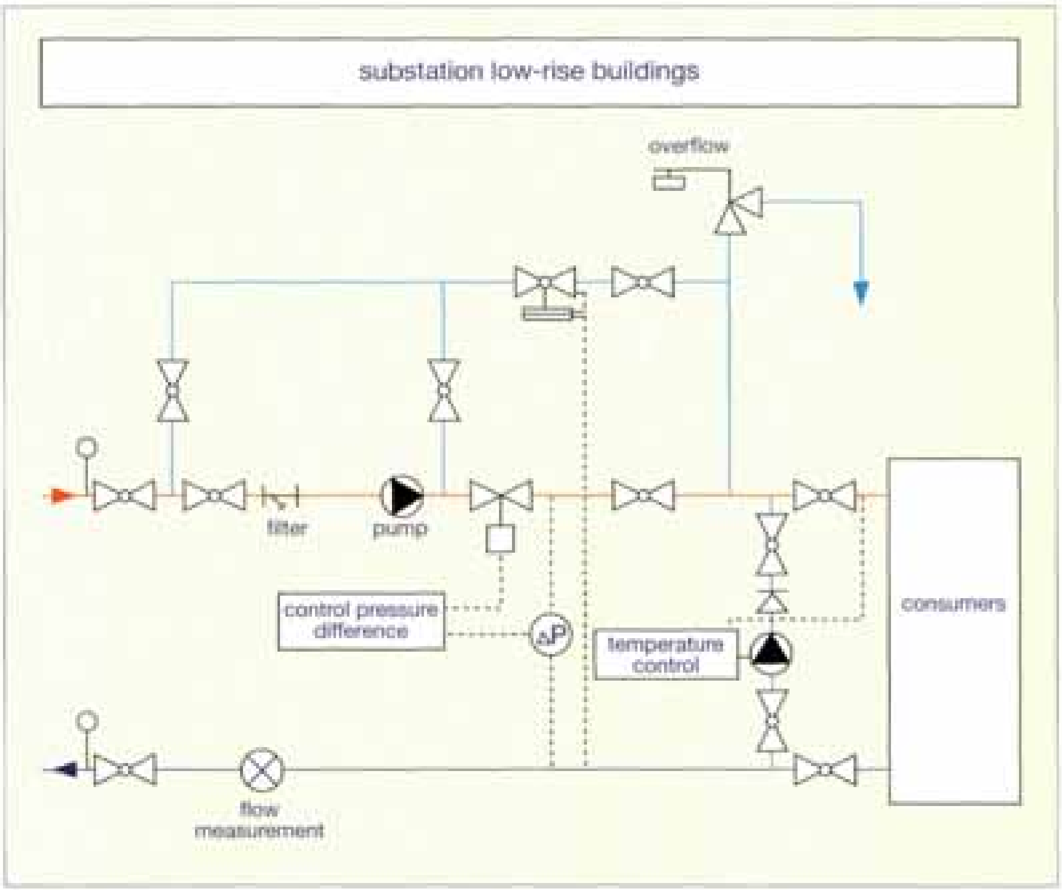
## 6.3 Control low-rise blocks

The low-rise blocks with 4 to 5 stories have an almost identical control station as the substation for high-rise blocks. The difference is that there are no booster pumps installed in these substations. Measurements are not recorded with exception of some blocks for indication.

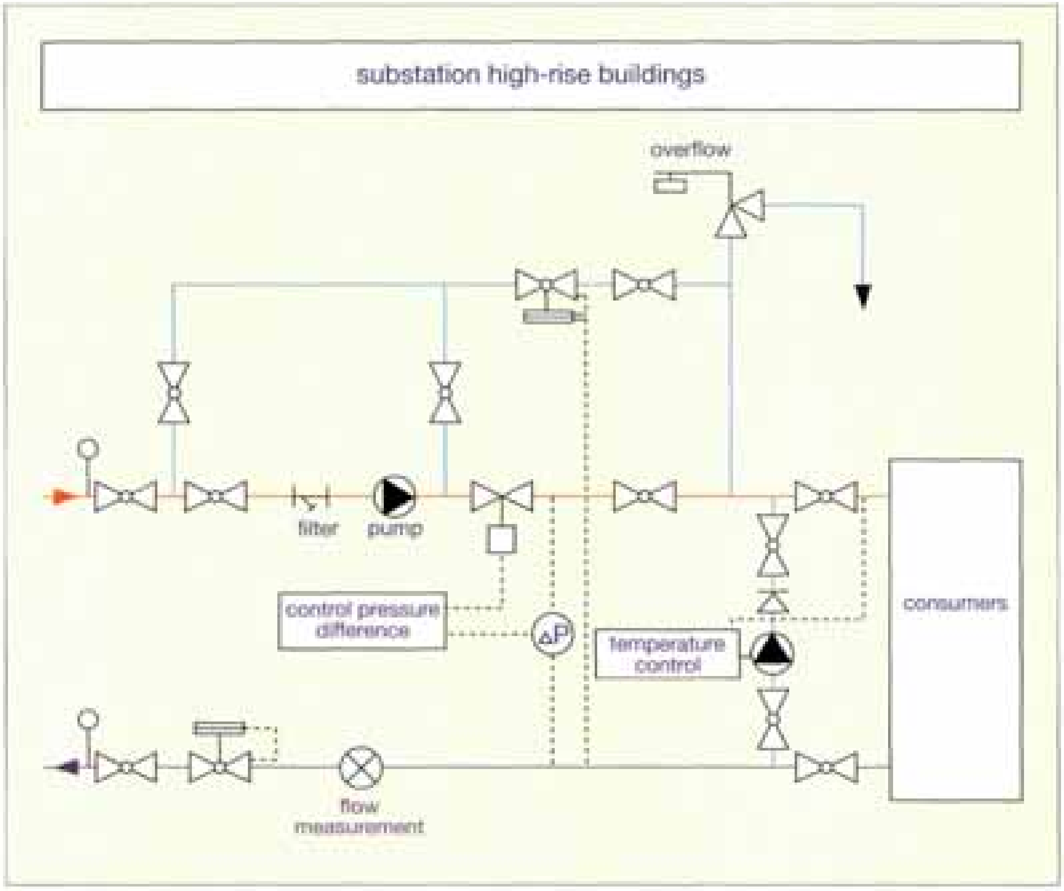
*Scheme substation low-rise buildings without pump.*



*Scheme substation low-rise buildings with pump.*



*Scheme substation high-rise buildings.*



## 6.4 Operational safety devices

Safety devices for low deficiency in operating the substations:

- pressure safeguarding by overflow valves with alarm signal of overflow to central computer;
- mechanical valves to close at diaphragm fracture;
- mechanical valves to open at diaphragm fracture;
- electrical drives to close at power break-down;
- alarm signal at high pressure difference;
- alarm signal at excessive supply temperature;
- alarm signal at excessive return temperature;
- alarm signal to warn when the connection to the central computer is damaged.

Alarm signals are reported to the service coordinator by the computer. The service coordinator can be reached by two telephone lines at home. For circumstantial information and collected data the computer is accessible by modem. Interfering is not possible. A mechanic and his stand-by may be contacted by mobile phone or semaphone.

# 7. Consumer controls

### 7.1 Controls one family houses

One family houses are build in blocks, what allows for pipelines through the house foundations with very short connecting pipelines. Therefore there is no need to build in a priority for hot water. The lay-out of the distribution net allows for a limitation of the pressure difference of 0.3 to 0.7 bar. Pressure difference controls are not installed.

All one family houses are directly connected to the distribution grid. Each connection has its own hot water unit. The temperature of the tapped water is regulated by a thermostatic valve. Space heating is regulated with a simple mix-injection system without further controls but a simple room thermostat.

Heat measurement is done with a static flow meter with electrical power supply. To prevent hot water consumption without metering, a main valve is installed which closes when the power is disconnected. The regulating valve for space heating may be set to a flow in accordance with the connection value of the house.

### 7.2 Controlling heating and hot water supply one family houses

Components for space heating in the standardized house heating unit (type TC-1300; page 57) for one family houses are:
- control valve with limited throughflow, activated by heat-motor and room thermostat (11);
- temperature sensor to switch the pump on and off (9);
- circulating pump (6);
- check valve (10).

The space heating functions when the room thermostat asks for heat because the room temperature is below the set value. Inside the thermostat a contact is closed and the heat-motor is activated to open the control valve (11) slowly.

The difference in pressure between supply and return of the district heating network allows heating water to flow through pipes and heating elements (radiators, convectors). After the throughflow the cooled down water returns through control valve (11) to the return of the district heating network.
If the returning water has a temperature of 50 °C or higher, the temperature sensor (9) switches on the circulating pump (6). This to secure that all the heating elements do get hot water.

The circulation pump (6) pumps the return water to the control valve with limited throughflow (11) and the rest recirculates through the check valve (10) to the supply line. In the supply line the water mixes to a lower supply temperature for space heating.

If the room thermostat measures a temperature above the set value, it switches of the heat-motor and the control valve (11) closes slowly. The circulating pump keeps running till the temperature in the heat supply line is below ca. 30 °C. Then also the pump switches off.

Because the control valve (11) operates slowly the heat supply will slowly decrease when the room thermostat switches off to slowly increase when the demand for heat is manifest again, often before the supply has been totally stopped.

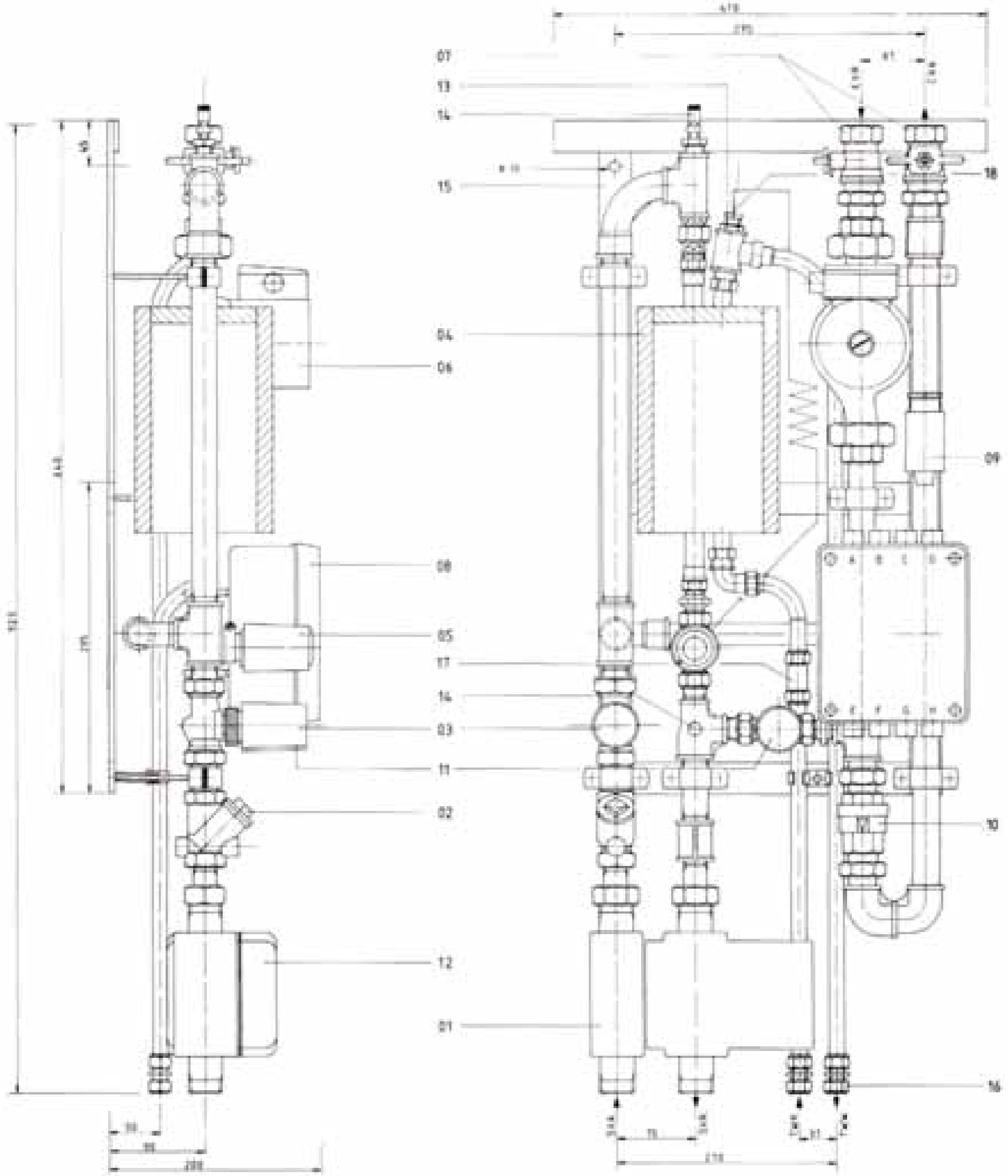
Components for hot water production:
- heat exchanger (4);
- temperature sensor for outgoing hot tap water (18);
- control valve with thermostatic head (5);
- tap water throughflow limiter (17);

Other parts:
- main valve with heat-motor (3);
- heat meter with flow meter, integrator and return temperature sensor (12);
- heat meter supply temperature sensor (1);
- filter (2).

### 7.3 Controls flatlets and small dwellings

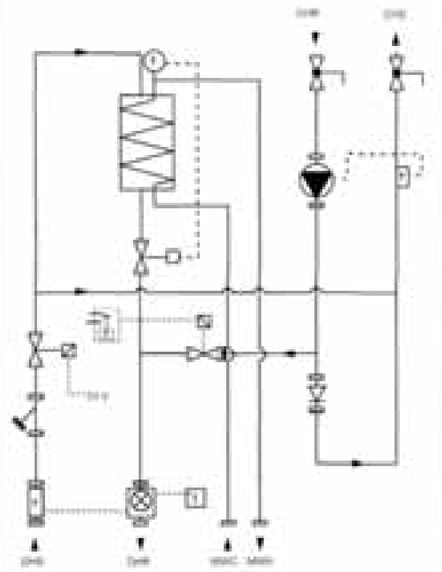
The offered pressure difference for apartments has a set value of 0.4 bar. Small apartments often suffer from to tiny supply pipelines for the heat supply. A preference selection for hot water is necessary. This is realized by a reduction valve to space heating with a set value. By this hydraulic limitation the district heating water prefers to flow through the heat exchanger for tap water when required.

The heat division for space heating is more simple so a circulation pump is not needed. Applying a central thermostatic radiator valve as room thermostat controls the flow for space heating. Electricity is not needed. The energy meter is a mechanical flow meter with battery power.



CABLE INLET CONNECTION BOX

| | | | |
|---|---|---|---|
| A | CH valve | DHS | district heating supply |
| B | heat cut unit | DHR | district heating return |
| C | DH valve | | |
| D | room thermostat | CHS | central heating supply |
| E | heat meter | CHR | central heating return |
| F | circulating pump | | |
| G | pump switch | MWW | tap water warm |
| H | line voltage 230 V | MWC | main water cold |



| part nr | qty | name | size | type | manufacturer |
|---|---|---|---|---|---|
| 18 | 01 | temperature sensor | | | |
| 17 | 01 | throughflow limiter | | | |
| 16 | 02 | straight coupling | 15 mm | RS 884 - 2 | [illegible] |
| 15 | 01 | frame | L= 30 x 5 | | |
| 14 | 02 | deaerating/air release valve | G 1/8" | | Schrader |
| 13 | 01 | stuffing box | G 1/2" | | |
| 12 | 01 | heat meter | G 3/4" | | Clorius |
| 11 | 01 | CH valve + heat motor | G 1/2" | X 7.521 28.004 | Bahi |
| 10 | 01 | no return valve | G 3/4" | | Valstop |
| 09 | 01 | pump switch | | | Sogas |
| 08 | 01 | connection box | | | |
| 07 | 02 | ball valve | G 3/4" | VSC8 | Kramer |
| 06 | 01 | circulating pump | G 3/4" | UPS 15 - 35 x 30 | Grundfos |
| 05 | 01 | thermo control | G 1/2" | R 462 L1 | [illegible] |
| 04 | 01 | heat exchanger | | DP 7 | Tipo-1 |
| 03 | 01 | DH valve + heat motor | G 3/4" | X 7.521 28.004 | Bahi |
| 02 | 01 | filter | G 3/4" | | |
| 01 | 01 | heat sensor | G 3/4" | | Clorius |

**PURMEREND**

**district heating unit**

**type TC - 13.00 up-side connection**

getr. PBJ d.d. 27 10 98

schaal 1 : 2

formaat A1

tek.nr. 3.013 13.00

JOS CLAESSENS TECHNISCHE PRODUCTEN B.V.

## 7.4 Controlling heating and hot water supply in small dwellings

The standard district heating unit for apartments type TC-1910 (see drawing on page 59, and the type TC-1300 with HR5 on pages 60 and 61) contains for space heating:

- thermostatic valve with capillary (1);
- reducing rectifier with set value (preference selection) (12).

The control functions if the sensor at the sensitive end of the capillary is set to the wanted room temperature and the control valve (1) takes a corresponding position. The difference in supply pressure and return pressure of the district heating water will cause a flow through the heating elements with open valves. The cooled return water goes through the reducing valve (12) as long as the pressure before the control valve (1) is higher than after, according to the set value of the reducing valve (12). If the control valve for hot water (9) is opened the pressure will decrease so far that there is no more difference in pressure over the control valve (1) for space heating.

Components for hot water production:

- heat exchanger (see drawing page 59) (3);
- heat sensor reacting on hot water outflow (6);
- control valve with thermostatic head (9);
- throughflow limiter (2).

Other parts:

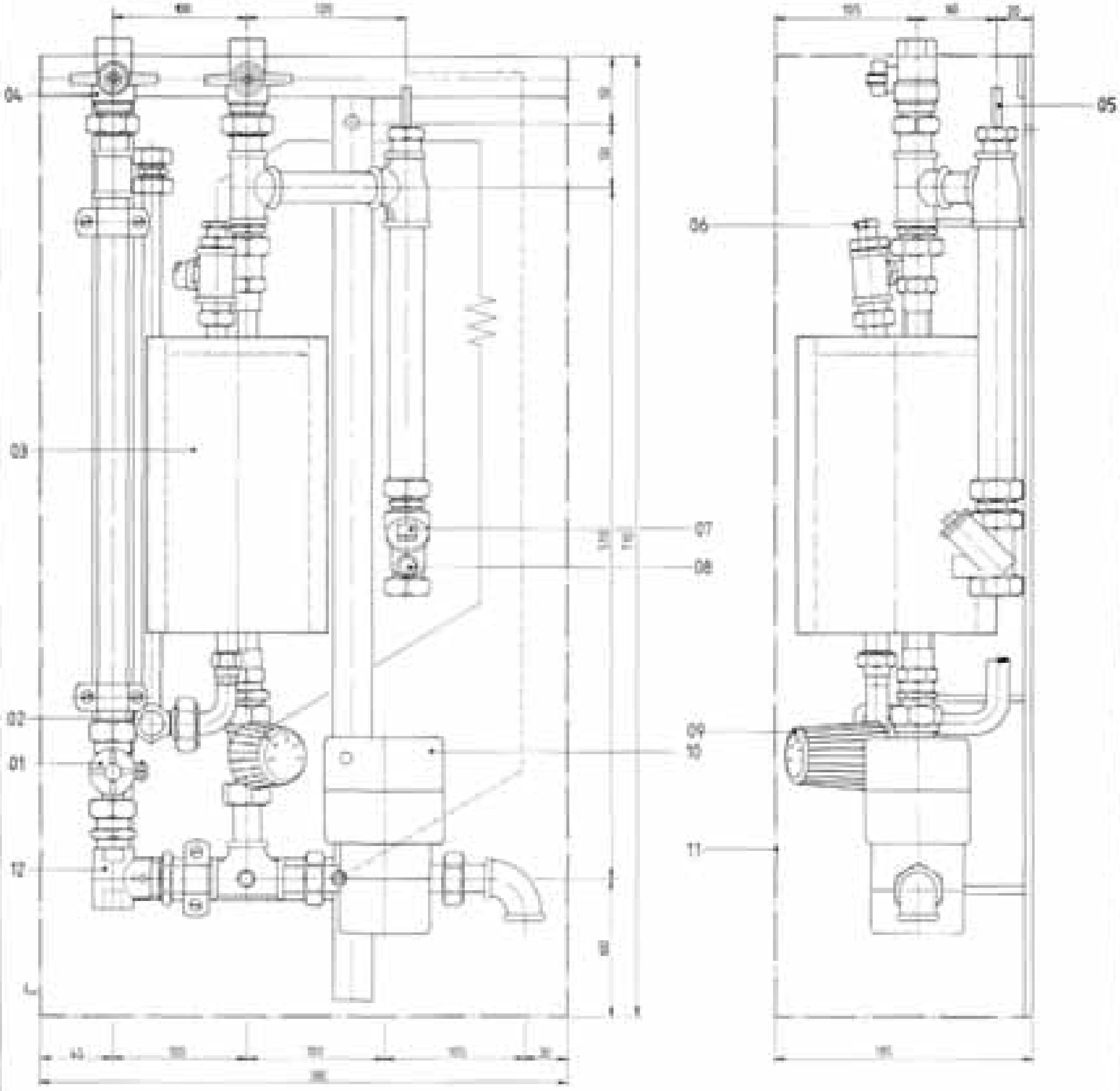
- filter (7);
- heat meter with flow meter, integrator and return temperature sensor (10);
- supply temperature sensor (5);

## 7.5 Controls utility buildings and major users

There is just one requirement for the category utility buildings and major users: the return temperature must be 50 °C or less. This temperature is guarded with a slow closing electrical or mechanical valve (see scheme at page 62).

## 7.6 Controlling hot water supply

The foundation of the domestic hot water supply is the need to provide tap water at a temperature of at least 55 °C at the nominal capacity of the heat exchanger. This is a realistic goal with a supply temperature of 70 °C and a main water temperature of 10 °C. Lower temperatures of the main water require higher temperatures of district heating water.
The temperature is controlled by a thermostatic valve steered by a sensor in the outgoing hot tap water side of the heat exchanger. This set-up secures keeping the heat exchanger at the right temperature when not tapping.



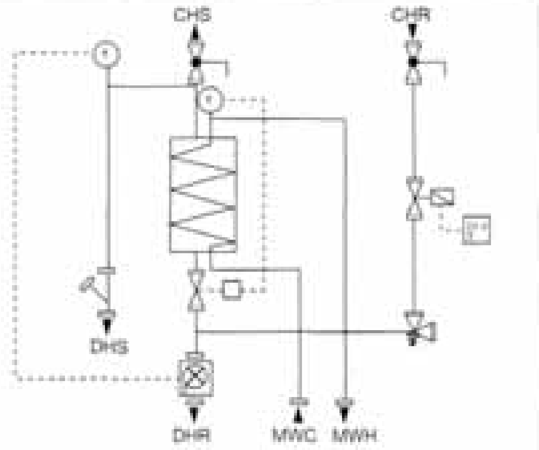
CABLE INLET CONNECTION BOX

A CH valve
B room thermostat
C heat meter/read-out unit

DHS district heating supply
DHR district heating return

CHS central heating supply
CHR central heating return

MWH tap water hot
MWC main water cold



| nr | quy | name | size | type | manufacturer |
|---|---|---|---|---|---|
| 12 | 01 | reduction valve | G 1/2" | | |
| 11 | 01 | cover 710x380x185 mm. | | | |
| 10 | 01 | heat meter | G 1/2" | | |
| 09 | 01 | therm.c control | G 1/2" | | |
| 08 | 02 | measuring/air release valve | G 1/8" | | |
| 07 | 01 | filter | G 3/4" | | |
| 06 | 01 | heat sensor HW | | | |
| 05 | 01 | heat sensor PT 100 | | | |
| 04 | 02 | valve | G 1/2" | | |
| 03 | 01 | heat exchanger | | DP - 7 | |
| 02 | 01 | throughflow limiter | G 1/2" | | |
| 01 | 01 | CH control valve | G 1/2" | | |

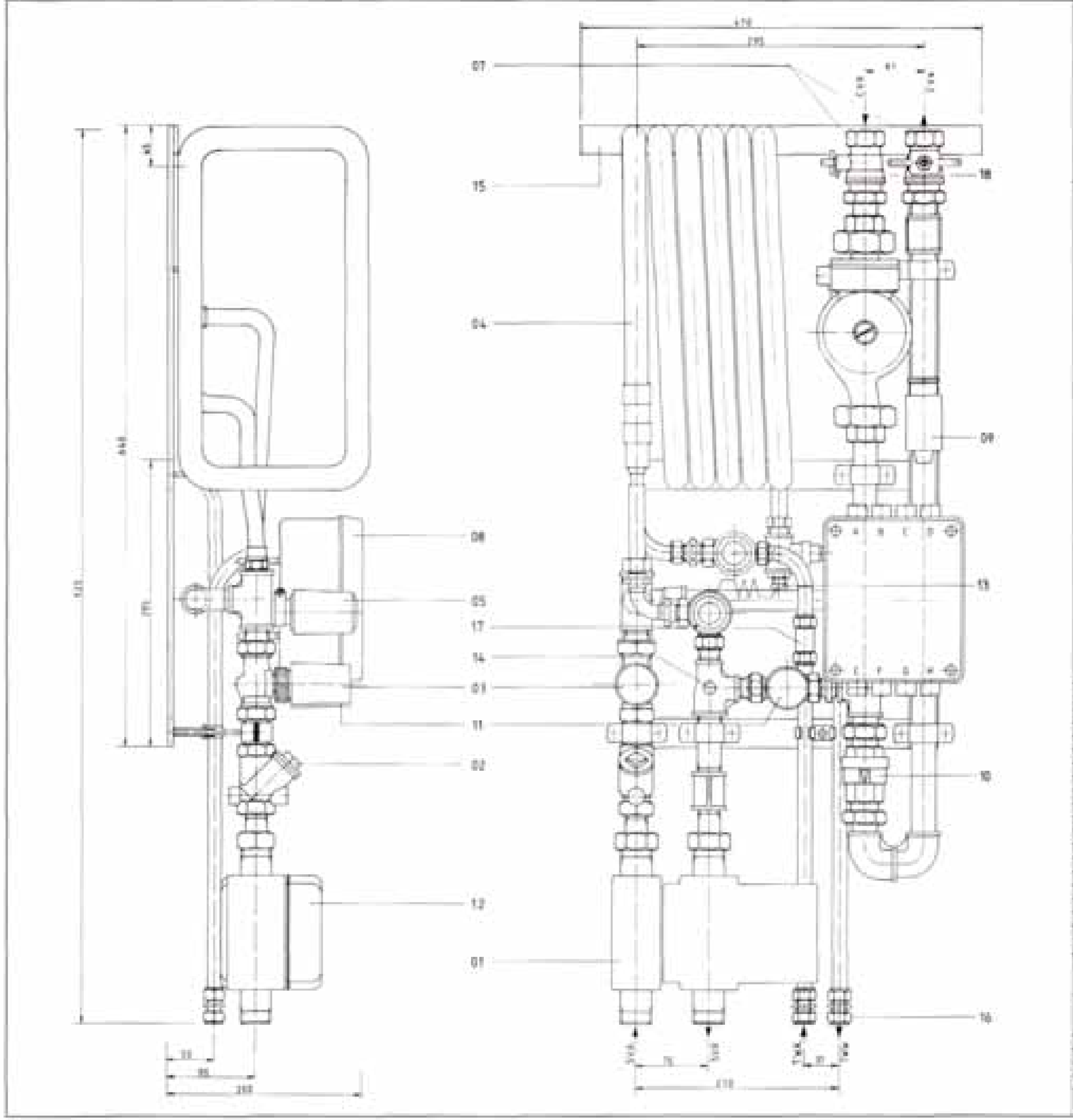
project
**PURMEREND**
**district heating unit**

part
**TC 19.10**

| | | |
|---|---|---|
| 1 | 13-01-91 | M.S. |
| PAR | WIJZIGING | GEZ. |

GET. PRJ
D.D. 24-01-89
GEC.
GEZ.
SCHAAL 1 : 2
REG.NR.
FORMAAT A 1
TEKNR. S.V.U.
AFDELING

**JOS CLAESSENS TECHNISCHE PRODUKTEN B.V.**



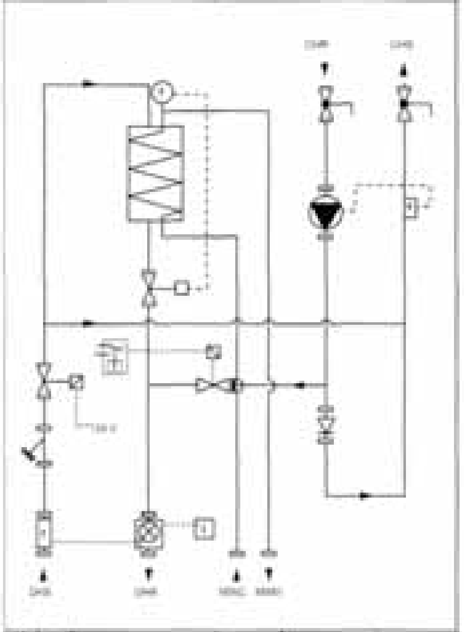
CABLE INLET CONNECTION BOX

A DH valve
B read-out unit
C DH valve
D room thermostat
E heat meter
F circulating pump
G pump switch
H line voltage 220 V

DHS district heating supply
DHR district heating return

CHS central heating supply
CHR central heating return

MWH tap water hot
MWC main water cold



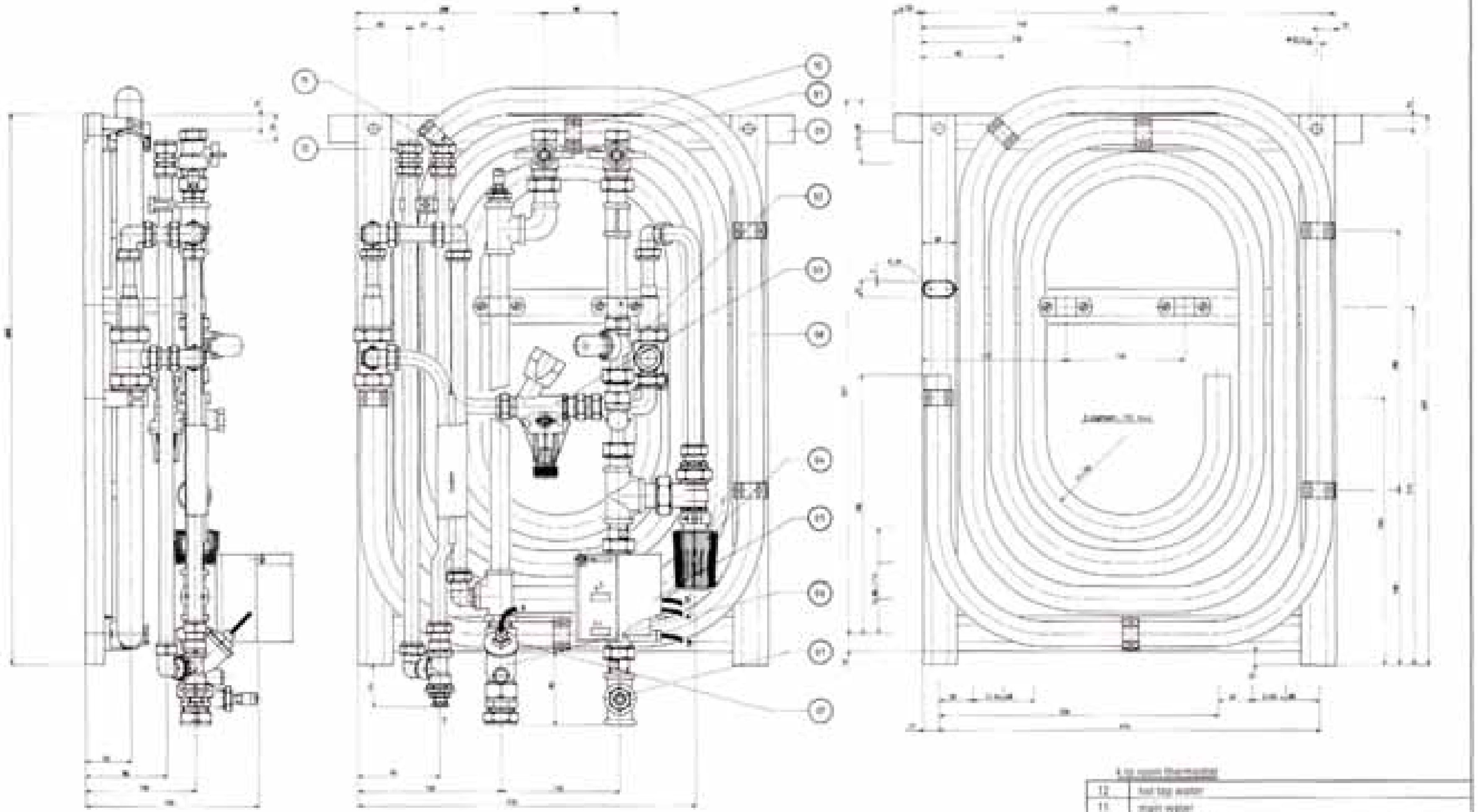
| part nr | qnt | description | size | type | manufacturer |
|---|---|---|---|---|---|
| 18 | 01 | temperature sensor | | | |
| 17 | 01 | throughflow limiter | | | |
| 16 | 02 | straight coupling | 15 mm | RS 844 - 2 | [illegible] |
| 15 | 01 | frame | ∟ 30 x 5 | | |
| 14 | 02 | measuring/air release valve | G 1/8" | | Schräder |
| 13 | 01 | stuffing box | G 1/2" | | |
| 12 | 01 | heat meter | G 3/4" | | Clorius |
| 11 | 01 | DH valve + heat motor | G 1/2" | X 7.121.26.024 | Beta |
| 10 | 01 | no-return valve | G 3/4" | | [illegible] |
| 09 | 01 | pump switch | | | [illegible] |
| 08 | 01 | connection box | | | |
| 07 | 01 | ball valve | G 3/4" | VSCK | [illegible] |
| 06 | 01 | circulating pump | G 3/4" | UPS 15 - 35 x 20 | Grundfos |
| 05 | 01 | thermo control | G 1/2" | R 462 L 1 | [illegible] |
| 04 | 01 | heat exchanger | | HRL | Jos Claessens |
| 03 | 01 | DH valve + heat motor | G 3/4" | X 7.121.26.024 | Beta |
| 02 | 01 | filter | G 3/4" | | |
| 01 | 01 | heat sensor | G 3/4" | | Clorius |

project
**PURMEREND**
**district heating unit**

part
**type TC - 13.00 up-side connection**

get. PRJ datum 27-10-88
schaal 1:2
formaat A1

JOS CLAESSENS TECHNISCHE PRODUKTEN B.V.



4 to room thermostat

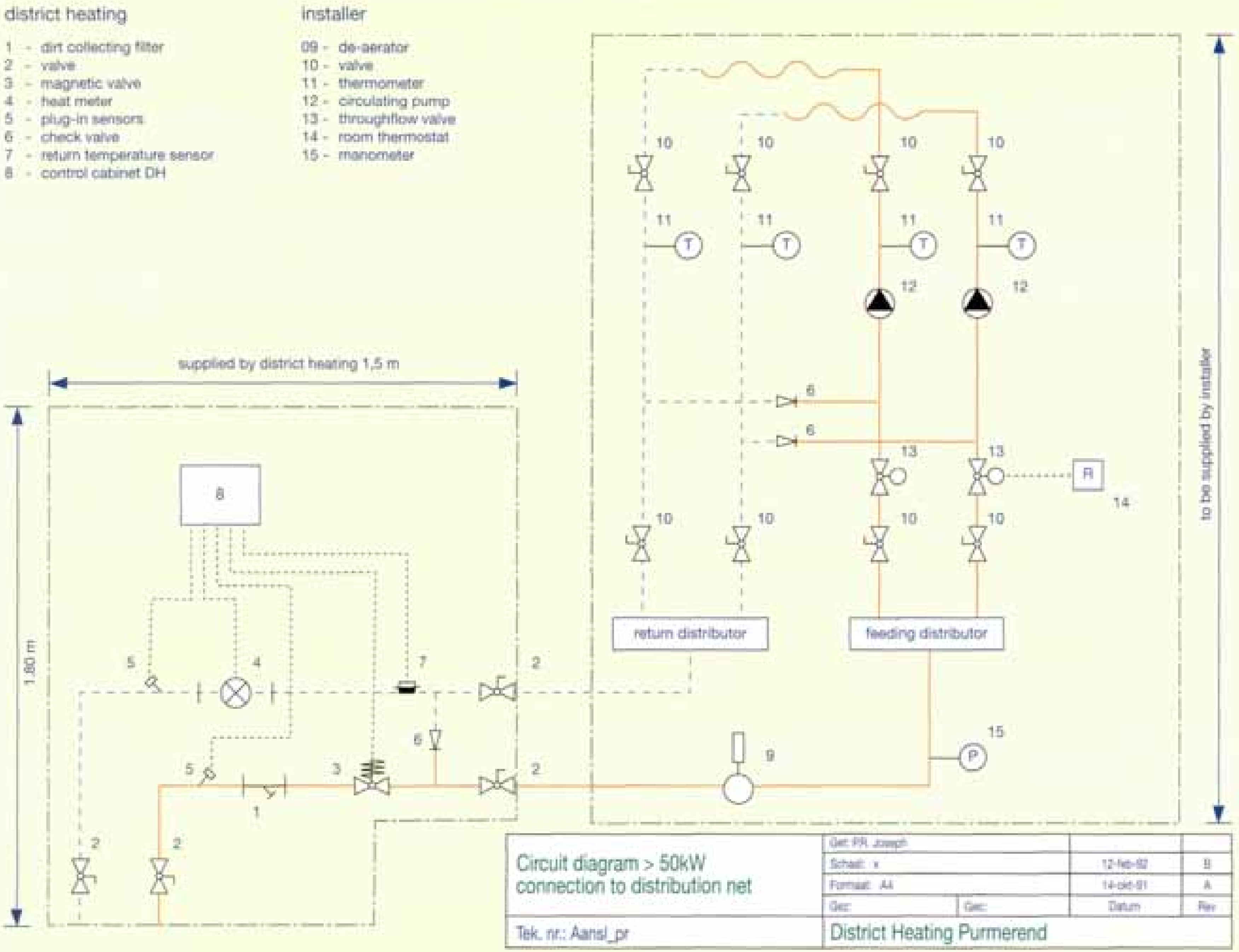
| | |
|---|---|
| 12 | hot tap water |
| 11 | main water |
| 10 | ball valve install |
| 09 | frame |
| 08 | heat exchanger |
| 07 | heat sensor |
| 06 | filter |
| 05 | meter |
| 04 | control valve |
| 03 | inlay combination |
| 02 | thermo controllable room thermostat (45° angle) |
| 01 | measuring valve e.g. de-aerator |
| part nr | description |

PURMEREND
district heating unit

COMPOSITION

schaal 1:2
formaat A3

JOS CLAESSENS TECHNISCHE PRODUKTEN B.V.



**district heating**

1 - dirt collecting filter
2 - valve
3 - magnetic valve
4 - heat meter
5 - plug-in sensors
6 - check valve
7 - return temperature sensor
8 - control cabinet DH

**installer**

09 - de-aerator
10 - valve
11 - thermometer
12 - circulating pump
13 - throughflow valve
14 - room thermostat
15 - manometer

Circuit diagram > 50kW
connection to distribution net

Get: P.R. Joseph
Schaal: x
Formaat: A4
Gez:
Gec:

| Datum | Rev |
|---|---|
| 12-feb-92 | B |
| 14-okt-91 | A |

Tek. nr.: Aansl_pr

District Heating Purmerend

# 8. Heat transport

## 8.1 Resistance Friction losses

Flow of water through pipelines creates frictional resistance. Enlarging the flow of water creates a squared value of resistance. The same goes for the cost to pump the water around.
The design of a piping system must take into account these costs and the costs for constructing, the cost of capital and the cost of maintenance. Big pipes create less resistance and are less expensive to operate, but are more expensive to buy.

Especially in case of district heating with strongly varying heat demand, design must be careful. The extreme circumstances need extra attention: there must be sufficient heat while the cost of operation is less relevant. This does not happen often.

Short pipelines create less resistance than long ones. An incentive to create many sources of heat nearby the consumers. District heating works often with only one source of heat because this is economically sound.

The creation of storage tanks on strategic locations is some kind of go between. They store heat at relative short distances from the consumers, if demand is not high, to supply it when demand is high. Transport costs are low this way.

## 8.2 Pressure requirement

Resistance in the pipelines creates loss of pressure. To compensate for these losses the pressure must be high at the head of the transport pipelines. The loss of pressure is equal in return pipelines when the diameters are equal. This also needs extra pressure. Besides, there is a need for extra pressure to compensate the losses in the heat delivery equipment. There has to be a difference in supply pressure and return pressure.

The difference will be highest at the beginning of the supply line and the end of the return line. The difference will be minimal at the end of the distribution pipelines where the supply line ends and the return line begins. The pressure at the end must be sufficient to overcome the resistances in the return line, i.e. the resistances in the control equipment and pipelines, but also of the water level in the storage tanks. The lowest return pressure depends on the temperature of the return water too. The pressure always has to be higher than the vapour pressure.

The heat exchanger needs a pressure difference of 0.3 bar (30 kPa) to function well. In tall apartment buildings this requires not only sufficient pressure to reach the top but also a controlled return. For these high buildings the supply pressure must be initially high. For an 11 story building this might be 3 bar (300 kPa). In these cases a separated circuit will be installed incorporating a controlled return check valve. The standard supply pressure will have to be increased by means of a pumping system.

Not only a sufficient pressure difference and a constant flow are required to feed the consumers installations, but the main transport system will also have to deal with all sorts of filters and control equipment with internal resistances. In the substations the supply pressure will be secured to provide sufficient pressure and pressure difference to fit the actual situation and to supply the farthest consumer. Supply pressures over 4 bar will be reduced.

Pumps and controlling equipment in substations need investment. Because these pumps are small the efficiency will be low. Building up pressure for a well operating system should be done by big and economically efficient pumps. Pumps will be rational in substations only if circumstances so require, e.g. at the end of a very long transport line.

## 8.3 Pumping stations

The pumping station at the CHPS, as well as the pumping station at the ABH and the storage tank in the township, are equipped with pumps. Besides, there is a central spare arrangement, pumps are identical as far as possible. Pumps are controlled in a way that ensures an economical turning speed under all conditions.

Transporting more or less water results in more or less resistance. Controlling heat transport presupposes a pressure difference that fits the heat demand and the friction of the pipelines. Increasing the flow increases the pressure, decreasing the flow decreases the pressure.

## 8.4 Operating

The initially expected demand of 20,000 housing equivalents requires 130 MW at peak demand. With a cooling down of 40 °C a flow is needed of no less than 2,800 $m^3$ per hour.

The main transport pipeline is operated as one entity. The resistance of every piece of the line is known. In the areas Purmer-North, Purmer-South and Gors-North the distribution is continued by a substation per section.

In the areas Overwhere and Wheermolen there is a substation per connected apartment building or utility building. The distribution is done inside.

For supplying heat to substations there are two extremes:

- supply all heat without the use of support pumps;
- supply all heat with use of as much as possible support pumps.

In circumstances with top demand there are three possible supply patterns:

- heat delivered by the CHPS and adjoining storage tanks
  - in the first extreme a starting pressure of 11 bar is needed with a pumping power of 1,100 kW.
  - in the second extreme a starting pressure of 5 bar will suffice, what takes a pumping power of 540 kW.
- ABH delivers the total supply for the needed top demand with support of all storage tanks
  - in the first extreme this requires a starting pressure of 14 bar with a pumping power of 1,650 kW.
  - in the second extreme a starting pressure of 6.5 bar and a pumping power of 790 kW suffices.
- heat delivered by a combination of CHPS and ABH without support of the storage tanks
  - In the first extreme this requires a starting pressure of 7 bar with a pumping power of 1,150 kW.
  - In the second extreme a starting power of 4.4 bar suffices with a pumping power of 760 kW.

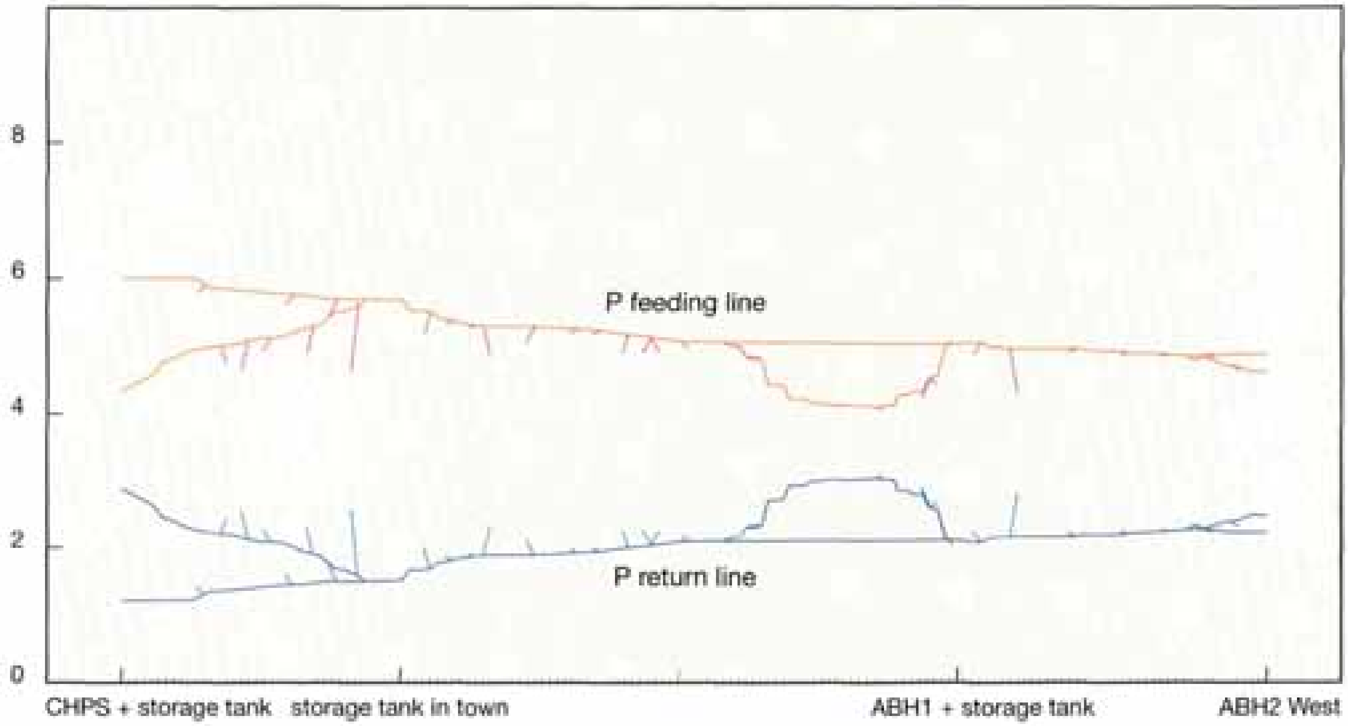
## 8.5 Operating standards

Practice will show a go between for the two extremes. For nine situations calculations are made with scenarios and graphs. See page 65 to 73.

Heat demand determines the flow in the total operation. The measured flow instructs the pumps to deliver the accompanying head pressure.

Recent calculations were made to accommodate 27,500 connections. The graphic results is shown on page 73.

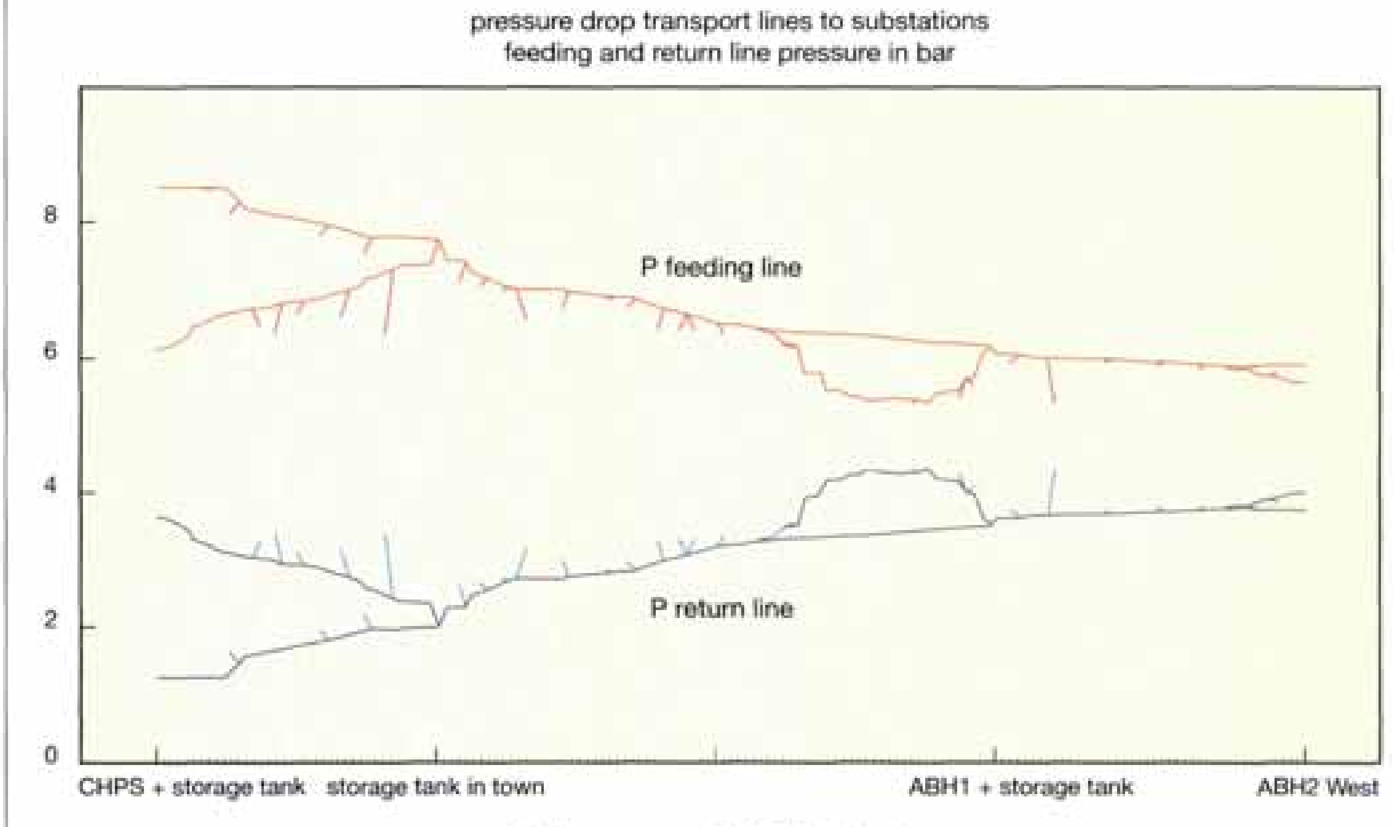
pressure drop transport lines to substations
feeding and return line pressure in bar



design pressure 1983, direct system

**Supply: ABH and three storage tanks, 65+20+20+25 MW**

| 20,000 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING-EQUIVALENTS | | $MW_{th}$ | kg/s | $m^3/h$ | bar | kW |
| connection value | | 200.0 | | | | |
| simultaneity | 65% | 130.0 | 691 | 2,488 | 6.0 | 406 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 50 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | 20.0 | | | | |
| sum CHPS location | | 85.0 | 452 | 1,627 | 6.0 | 278 |
| storage tank 2 located in town | | 20.0 | 106 | 383 | 5.7 | 61 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 4.6 | 0 |
| storage tank 3 at ABH1 location | | 25.0 | | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | 25.0 | 133 | 479 | 5.1 | 66 |
| ABH2 West | | 0.0 | 0 | 0 | 4.9 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 4.1 | |
| highest return pressure return transport line | | | | | 3.1 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

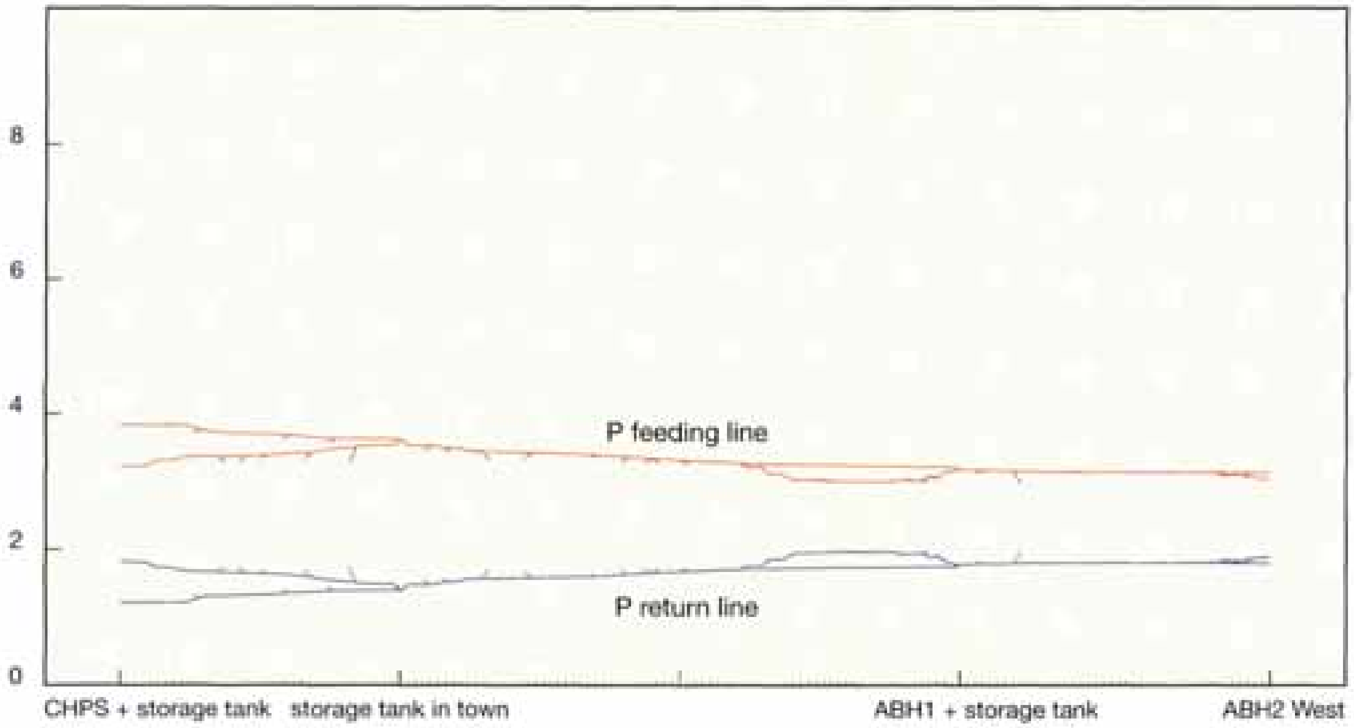


design pressure 1983, direct system

**Supply from one point: CHPS location**

| 20.000<br>HOUSING-EQUIVALENTS | | power<br>MW$_{th}$ | flow<br>kg/s | <br>m³/h | pressure<br>bar | pumping power<br>kW |
|---|---|---|---|---|---|---|
| connection value | | 200.0 | | | | |
| simultaneity | 65% | 130.0 | 691 | 2,488 | 8.5 | 647 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 50 °C | | | | | |
| **Heat supply**: | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | | 65.0 | | | |
| sum CHPS location | | 130.0 | 691 | 2,488 | 8.5 | 647 |
| storage tank 2 located in town | | 0.0 | 0 | 0 | 7.4 | 0 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 6.3 | 0 |
| storage tank 3 at ABH1 location | | | 0.0 | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | 0.0 | 0 | 0 | 6.1 | 0 |
| ABH2 West | | 0.0 | 0 | 0 | 5.9 | 0 |
| **Residual pressures**: | | | | | | |
| lowest residual pressure feeding transport line | | | | | 5.3 | |
| highest return pressure return transport line | | | | | 4.4 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

pressure drop transport lines to substations
feeding and return line pressure in bar

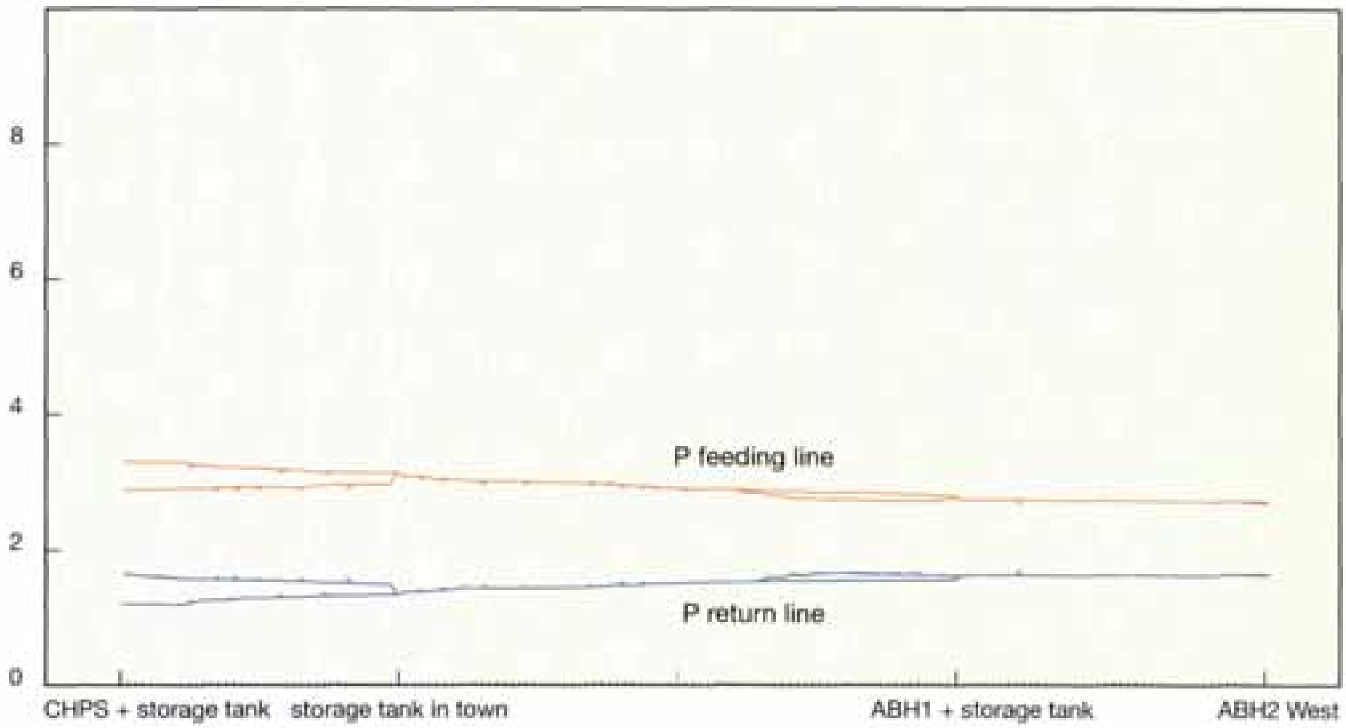


design pressure 1983, direct system

**Supply: exclusively by CHPS, demand 65 MW$_{th}$**

| 20,000<br>HOUSING-EQUIVALENTS | | power<br>MW$_{th}$ | flow<br>kg/s | <br>m³/h | pressure<br>bar | pumping power<br>kW |
|---|---|---|---|---|---|---|
| connection value | | 200.0 | | | | |
| simultaneity | 33% | 65.0 | 346 | 1,244 | 3.8 | 115 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 50 °C | | | | | |
| **Heat supply**: | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | | 0.0 | | | |
| sum CHPS location | | 65.0 | 346 | 1,244 | 3.8 | 115 |
| storage tank 2 located in town | | 0.0 | 0 | 0 | 3.5 | 0 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 3.2 | 0 |
| storage tank 3 at ABH1 location | | | 0.0 | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | 0.0 | 0 | 0 | 3.2 | 0 |
| ABH2 West | | 0.0 | 0 | 0 | 3.2 | 0 |
| **Residual pressures**: | | | | | | |
| lowest residual pressure feeding transport line | | | | | 3.0 | |
| highest return pressure return transport line | | | | | 2.0 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

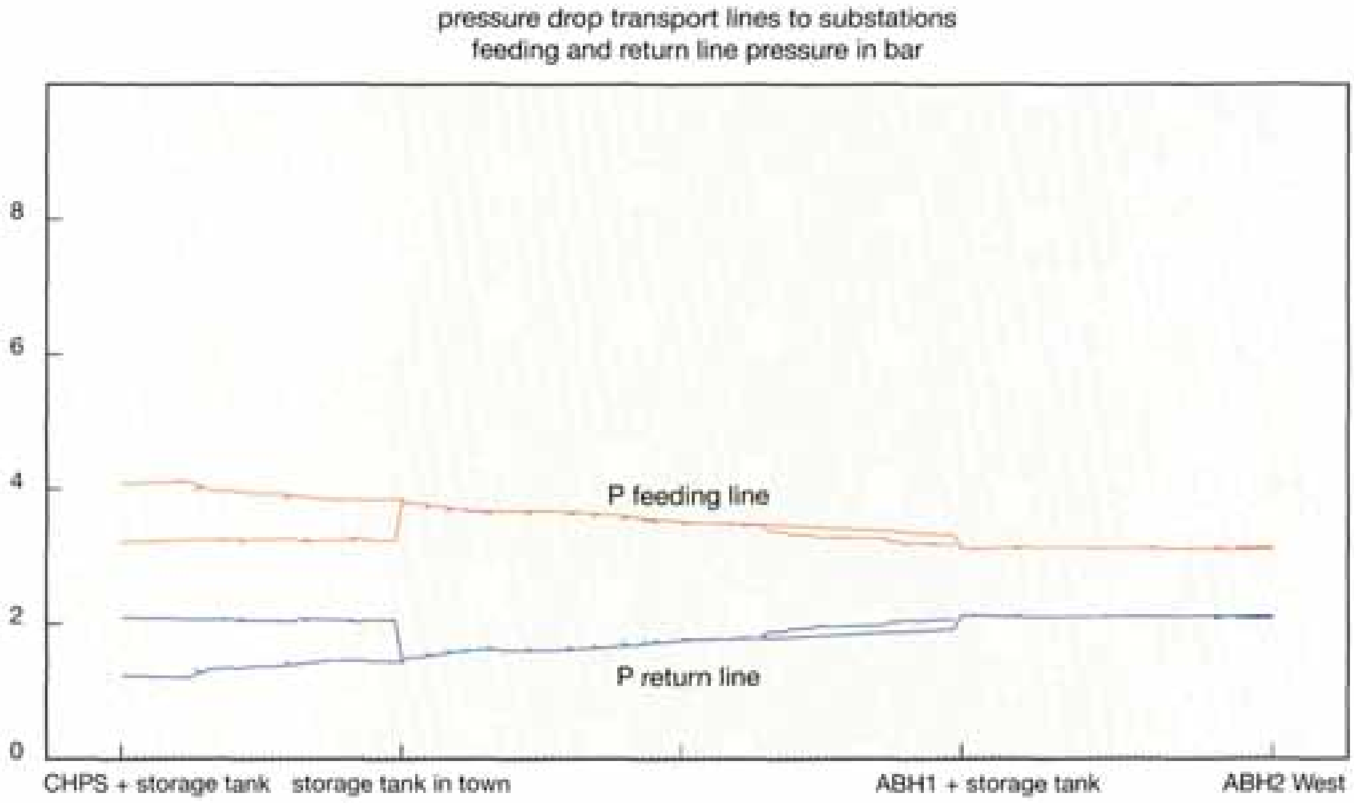
pressure drop transport lines to substations
feeding and return line pressure in bar



design pressure 1983, direct system

**Supply: by CHPS, meanwhile loading storage tanks**

| 20,000 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING-EQUIVALENTS | | $MW_{th}$ | kg/s | $m^3/h$ | bar | kW |
| connection value | | 200.0 | | | | |
| simultaneity | 20% | 40.0 | 213 | 766 | 3.3 | 97 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 50 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | | -8.3 | | | |
| sum CHPS location | | 56.7 | 301 | 1,085 | 3.3 | 81 |
| storage tank 2 located in town | | -8.3 | -44 | -159 | 3.0 | 8 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 2.9 | 0 |
| storage tank 3 at ABH1 location | | | -8.3 | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | -8.3 | -44 | -159 | 2.8 | 8 |
| ABH2 West | | -0.0 | -0 | -0 | 2.8 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 2.7 | |
| highest return pressure return transport line | | | | | 1.8 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

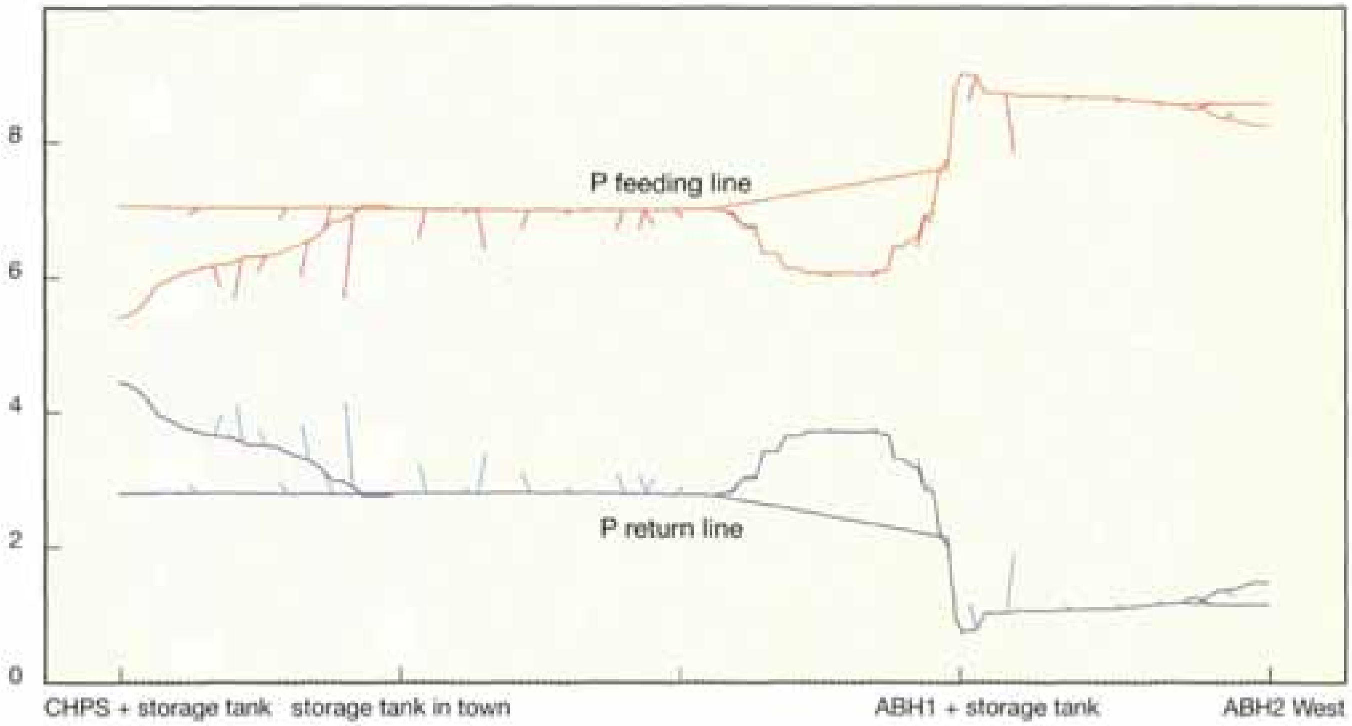


design pressure 1983, direct system

**Supply: by CHPS, meanwhile loading storage tanks**

| 20,000 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING-EQUIVALENTS | | MW$_{th}$ | kg/s | m$^3$/h | bar | kW |
| connection value | | 200.0 | | | | |
| simultaneity | 10% | 19.0 | 152 | 546 | 4.1 | 191 |
| feeding temperature | 85 °C | | | | | |
| return temperature | 55 °C | | | | | |
| Heat supply: | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | | -15.3 | | | |
| sum CHPS location | | 49.7 | 396 | 1,426 | 4.1 | 147 |
| storage tank 2 located in town | | -15.3 | -122 | -440 | 3.2 | 22 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 3.2 | 0 |
| storage tank 3 at ABH1 location | | | -15.3 | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | -15.3 | -122 | -440 | 3.1 | 22 |
| ABH2 West | | -0.0 | -0 | -0 | 3.1 | 0 |
| Residual pressures: | | | | | | |
| lowest residual pressure feeding transport line | | | | | 3.1 | |
| highest return pressure return transport line | | | | | 2.2 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

pressure drop transport lines to substations
feeding and return line pressure in bar

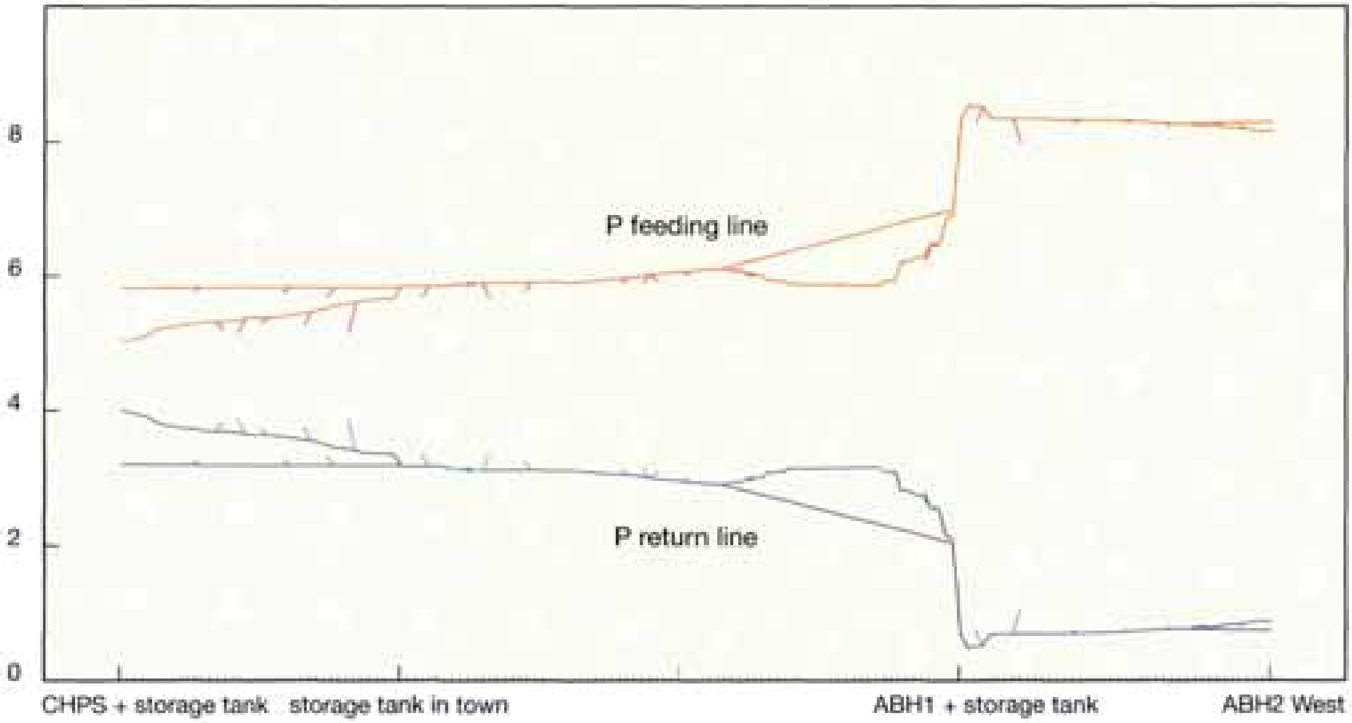


design pressure 1983, direct system

**Supply: by ABH and storage tanks**

| 20,000 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING-EQUIVALENTS | | $MW_{th}$ | kg/s | $m^3/h$ | bar | kW |
| connection value | | 200.0 | | | | |
| simultaneity | 65% | 130.0 | 778 | 2,799 | 7.0 | 704 |
| feeding temperature | 90 °C | | | | | |
| return temperature | 50 °C | | | | | |
| **Heat supply:** | | | | | | |
| **CHPS** | | 0.0 | | | | |
| storage tank 1 at CHPS location | | | 23.3 | | | |
| sum CHPS location | | 23.3 | 139 | 502 | 7.0 | 104 |
| storage tank 2 located in town | | 23.3 | 139 | 502 | 7.0 | 104 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 5.6 | 0 |
| storage tank 3 at ABH1 location | | 23.4 | | | | |
| ABH1 | | 60.0 | | | | |
| sum location ABH1 | | 83.4 | 499 | 1,796 | 9.0 | 497 |
| ABH2 West | | 0.0 | 0 | 0 | 8.6 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 5.4 | |
| highest return pressure return transport line | | | | | 4.4 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

pressure drop transport lines to substations
feeding and return line pressure in bar

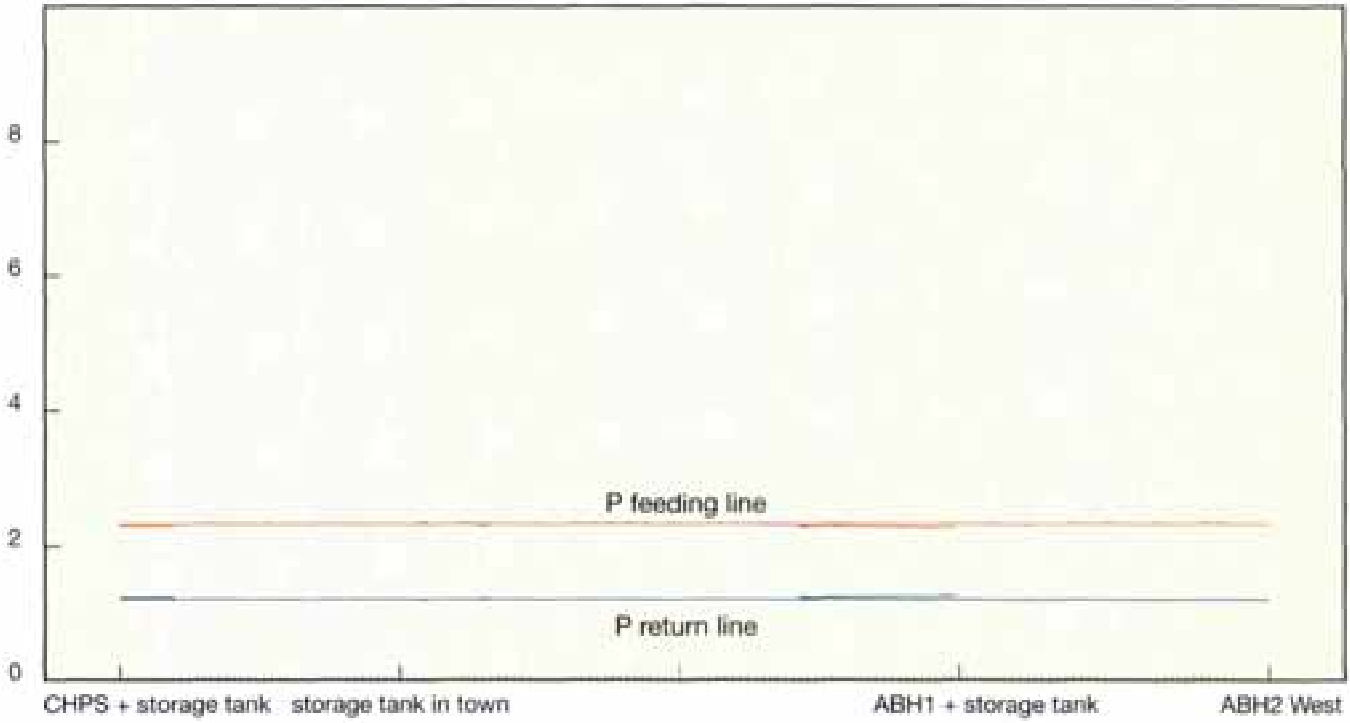


design pressure 1983, direct system

**Supply: by ABH**

| 20,000<br>HOUSING-EQUIVALENTS | | power<br>$MW_{th}$ | flow<br>kg/s | <br>$m^3/h$ | pressure<br>bar | pumping power<br>kW |
|---|---|---|---|---|---|---|
| connection value | | 200.0 | | | | |
| simultaneity | 30% | 60.0 | 479 | 1,723 | 5.8 | 445 |
| feeding temperature | 85 °C | | | | | |
| return temperature | 55 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 0.0 | | | | |
| storage tank 1 at CHPS location | | | 0.0 | | | |
| sum CHPS location | | 0.0 | 0 | 0 | 5.8 | 0 |
| storage tank 2 located in town | | 0.0 | 0 | 0 | 5.6 | 0 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 5.1 | 0 |
| storage tank 3 at ABH1 location | | 0.0 | | | | |
| ABH1 | | 60.0 | | | | |
| sum location ABH1 | | 60.0 | 479 | 1,723 | 8.5 | 445 |
| ABH2 West | | 0.0 | 0 | 0 | 8.2 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 5.0 | |
| highest return pressure return transport line | | | | | 4.0 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

pressure drop transport lines to substations
feeding and return line pressure in bar

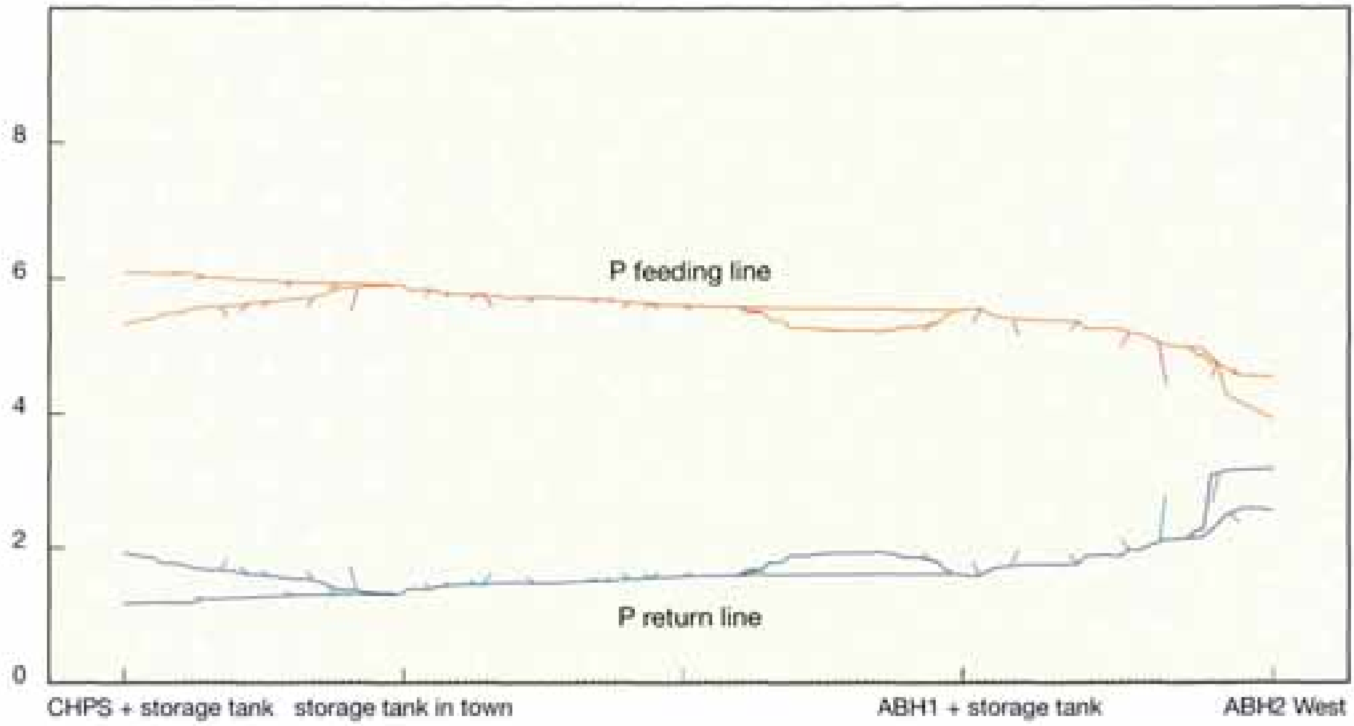


design pressure 1983, direct system

**Supply: three storage tanks in night load**

| 20,000<br>HOUSING-EQUIVALENTS | | power<br>MW$_{th}$ | flow<br>kg/s | <br>m³/h | pressure<br>bar | pumping power<br>kW |
|---|---|---|---|---|---|---|
| connection value | | 200.0 | | | | |
| simultaneity | 6% | 12.0 | 82 | 295 | 2.3 | 12 |
| feeding temperature | 85 °C | | | | | |
| return temperature | 50 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 0.0 | | | | |
| storage tank 1 at CHPS location | | 4.0 | | | | |
| sum CHPS location | | 4.0 | 27 | 98 | 2.3 | 4 |
| storage tank 2 located in town | | 4.0 | 27 | 98 | 2.3 | 4 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 2.3 | 0 |
| storage tank 3 at ABH1 location | | | 4.0 | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | 4.0 | 27 | 98 | 2.3 | 4 |
| ABH2 West | | 0.0 | 0 | 0 | 2.3 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 2.3 | |
| highest return pressure return transport line | | | | | 1.2 | |
| smallest pressure difference in substations HW | | | | | 1.0 | |
| sum of pumping power needed in substations | | | | | | 0 |

pressure drop transport lines to substations
feeding and return line pressure in bar



design pressure 1983, direct system

**Supply: by CHPS and storage tanks. 175% of daily mean**

| 27,500 | | power | flow | | pressure | pumping power |
|---|---|---|---|---|---|---|
| HOUSING-EQUIVALENTS | | $MW_{th}$ | kg/s | $m^3/h$ | bar | kW |
| connection value | | 275.9 | | | | |
| simultaneity | 40% | 110.4 | 528 | 1,901 | 6.0 | 338 |
| feeding temperature | 95 °C | | | | | |
| return temperature | 45 °C | | | | | |
| **Heat supply:** | | | | | | |
| CHPS | | 65.0 | | | | |
| storage tank 1 at CHPS location | | 0.0 | | | | |
| sum CHPS location | | 65.0 | 311 | 1,120 | 6.0 | 191 |
| storage tank 2 located in town | | 15.1 | 72 | 260 | 5.9 | 43 |
| Vennen, bivalent connection | no | 0.0 | 0 | 0 | 5.3 | 0 |
| storage tank 3 at ABH1 location | | | 30.0 | | | |
| ABH1 | | 0.0 | | | | |
| sum location ABH1 | | 30.0 | 144 | 517 | 5.6 | 80 |
| ABH2 West | | 0.3 | 1 | 4 | 3.5 | 0 |
| **Residual pressures:** | | | | | | |
| lowest residual pressure feeding transport line | | | | | 3.5 | |
| highest return pressure return transport line | | | | | 3.7 | |
| smallest pressure difference in substations HW | | | | | 0.9 | |
| sum of pumping power needed in substations | | | | | | 23 |

# 9. Safeguarding

## 9.1 Overall safeguarding

The safeguarding of the total transport and distribution system consists of six basic components:

- safeguarding for excess pressure in the pumping stations and consequently the supply transport pipelines;
- safeguarding for excess pressure after the substations;
- safeguarding for excess pressure in the return transport pipelines;
- safeguarding for overflow of the storage tanks;
- safeguarding for draining the storage tanks;
- safeguarding for overflow from one storage tank to another.

The data of the total system of pumping stations, substations and storage tanks are continuously, with ten minutes intervals, checked through a communication system and registered. Deviations are selected on gravity and then registered, and, if action is necessary reported to the duty service coordinator.

Important faults must be reset by phone. If the reset is not handled within a certain period of time, the fault message is communicated to a second and a third person.

Fault messages are related to e.g.:

- low supply temperature;
- high return temperature;
- high or low pressure difference.

## 9.2 Safeguarding high pressure in pumping stations

The safeguarding in the pumping stations for exceeding the maximally allowed supply pressure to the transport pipelines consists of two systems.

- The first is an electronic protection in the pump controls to prevent exceeding a pre-arranged value which turns down the speed of speed-controlled pumps and closes the supply valves of pumps with set turning speed.
- The second is a mechanical protection, whereby the excess pressure relief valves in the pumping stations take care of a return flow in the return pipe to the storage tanks. This last protection is set at a higher value than the first one and sends a signal when it starts to operate.

## 9.3 Safeguarding high pressure in substations

The safeguarding of the maximum allowed supply pressure in the distribution grid after a substation in dwellings or high apartment buildings consists also of two systems.

- If the maximum pressure is exceeded, the system is electrically protected by disconnecting the control valve. This valve then closes and isolates the substation from the supply transport line. The mechanical protection operates with an excess pressure relief valve which drains in the sewer.
- Here the mechanical device is set to a higher value too. If the safeguards are called upon the central computer is informed.

## 9.4 Safeguarding high pressure in return pipelines

Because the total control of flow and pressure in the substations in residential districts depends on the pressure in the return transport pipelines, it is necessary to guard the return pressure. This is done in three ways.

- When supplying from a storage tank an electronic system adjusts the delivery according to the return pressure.
  This reduces the return flow and thus the return pressure.
- A mechanical system operates with an excess pressure relief valve in all storage tank installations which drains an excess return pressure to the nearest storage tank.
- If a storage tank is inactive the mechanical protection is still on stand-by. Besides, separate electronic controls open the return valve to the storage tank when the pressure is undesirable high.

The mechanic safeguard is set at a higher level than the electronic ones. An internal overflow occurs when a storage tank starts to supply and there is, temporarily, no return flow possible to that storage tank. As soon as the electronically controlled balance is active, within minutes, the situation will be normalized.

## 9.5 Safeguarding overflow of storage tanks

Overflow of storage tanks means loss of water which has to be prevented. The controls for unloading and loading hot or cold water keeps the level constant within limits. Outgoing hot water may endanger the surrounding and the environment and therefore there is a protection for such events. The storage tanks are equipped with an electronic (pressure) level measurement.

If too high a level occurs two steps are taken, depending on circumstances:

- While unloading, the return valve of the storage tank closes slowly. Because the pumps continue pumping the level slowly decreases;
- While loading the intake valve of the storage tank closes slowly. Now the level decreases because the outgoing flow lags behind and pumping continues.

If the level gets too high a fault signal is sent.

## 9.6 Safeguarding for draining storage tanks

The whole system of storage tanks and transport pipelines has to be filled in order to operate all the connected components. Too little water will shut-off the tanks one by one. In case of a pipeline fracture it is possible that the tanks in operation drain. The non-operating storage tanks are automatically disconnected from the pipelines by valves. Exceeding the maximally allowed flow out of the storage tanks is converted to an alarm signal that disconnects the storage tanks from the pipelines. This is also signalled to the central computer.

## 9.7 Safeguarding equalizing of storage tanks

The content of a storage tank is autonomously held on level by controlled pumping. When a power failure occurs the valves close, otherwise the storage tanks could empty themselves in each other because of differences in static height. The most important control valves which disconnect the storage tanks from the pipelines are therefore of a fail-safe design, closing when power is disconnected or not available. Pumps are equipped with check valves to prevent unwanted throughflow.

# 10. Adjustments to developments

### 10.1 Introduction

Designing, implementing and developing the project, new developments opened new management opportunities as well as they imposed restraints. These developments concern telecommunications, pipeline prices and techniques, heat loss considerations and limitation of the return temperature.

In the district heating project of Purmerend originally the choice was made for a totally autonomous control system, influenced only by heat demand and heat production. Telecommunications does not have a controlling function. The simple but sufficient communication network was incorporated to read and register data and to update controlling parameters if and when required. This allows insight into the functioning of the total system.

### 10.2 Telecommunications options

The communications system is only used to transmit data. The data are control files and parameters. The automatically read data are processed by a central computer and recorded. Exceeding set upper and lower limits are registered and eventually transformed to alarm signals. Interruptions of the communication system are reported and registered. Received signals may be transformed to messages transmitted through telephone lines. When the communication system is out of order all controls operate autonomously.

The telecommunication system is also fit to instruct the equipment on a limited scale. The central computer is than used to change parameters and to activate the system.

The changeable parameters are fit to:
- activate or de-activate storage. This is done by changing the values of controlling temperatures.
- change pressure differences in substations to change the outgoing flow. This is done by changing the parameters or the curve that controls the pressure difference in relation to flow.

The operation of the district heating system may be checked and changed at any moment out of any location by use of the central computer, modem, telephone line and laptop by reading or inserting new parameters.

### 10.3 Costs of the pipeline system

While the project was developing the prices of pre-insulated pipe and accessories, existing of steel pipes, polyurethane insulation and polyethylene jackets, kept rising. In the beginning of the eighties the many pipes were imported from Scandinavian countries, Denmark in particular, later from Germany. From 1985 these pipes were also manufactured in the Netherlands but without any positive influence on prices. During the same period the wages in the building sector were also rising. The work on pipelines, like welding and fitting, was paid according to the lower wages agreement for metal workers.

The costs of a double pipeline are calculated per running meter, including material, constructing and finishing, an average set of curves, expansion loops and valves included. These complete figures make an overall comparison possible.

The costs of a double pipeline per running meter, including material, constructing and finishing, an average set of curves, expansion loops and valves included, were in 1982:

| | **Single insulation** | **Double insulation** |
|---|---|---|
| DN 100 | 700 | 720 |
| DN 125 | 800 | 820 |
| DN 150 | 900 | 930 |
| DN 200 | 1,100 | 1,150 |
| DN 250 | 1,300 | 1,360 |
| DN 300 | 1,500 | 1,570 |
| DN 400 | 1,900 | 1,990 |
| DN 500 | 2,300 | 2,400 |
| DN 600 | 2,800 | 2,930 |

In 1985 these cost were increased to:

| | **Single insulation** | **Double insulation** |
|---|---|---|
| DN 100 | 790 | 820 |
| DN 125 | 910 | 940 |
| DN 150 | 1,030 | 1,060 |
| DN 200 | 1,250 | 1,310 |
| DN 250 | 1,480 | 1,550 |
| DN 300 | 1,710 | 1,790 |
| DN 400 | 2,170 | 2,270 |
| DN 500 | 2,620 | 2,740 |
| DN 600 | 3,190 | 3,340 |

## 10.4 Present costs of district heating systems

In the second half of the eighties improvements in the installing of pipes were common procedure. In many cases the pipe diameters were limited to DN 300. For these pipes needed no government approved testing according to steam codes, even if the applied temperatures exceeded 100 °C. The pipelines were calculated, installed, and pressure tested in accordance with the steam code. Extreme expansion loops below earth were restricted. Pre-tensioning, installing pre-heated became an accepted method while pipelines were also laid in wide curves to avoid tension and stress.

The implementation of these techniques allowed a cost development for installing pipes in 1992 to:

| | **Single insulation** | **Double insulation** |
|---|---|---|
| DN 100 | 900 | 920 |
| DN 125 | 1,020 | 1,040 |
| DN 150 | 1,150 | 1,170 |
| DN 200 | 1,290 | 1,350 |
| DN 250 | 1,510 | 1,560 |
| DN 300 | 1,740 | 1,800 |
| DN 400 | 2,210 | 2,280 |
| DN 500 | 2,670 | 2,760 |
| DN 600 | 3,400 | 3,500 |

Pipelines above ground, in creeping spaces below houses and fitted pipelines, insulated with pre-moulds and moist repellent coating, show a comparable picture:

| | **1982** | **1992** |
|---|---|---|
| DN 40 | 170 | 220 |
| DN 50 | 190 | 240 |
| DN 65 | 230 | 290 |
| DN 80 | 290 | 340 |
| DN 100 | 285 | 400 |
| DN 125 | 410 | 510 |

The costs are an indication for the development. In certain cases the operating pressure may be low and pipes with thinner walls may be used resulting in lower costs. A solid sand foundation with a low ground water level will induce lower costs than muddy clay with a high ground water level. The installation of pipelines in existing dwellings may induce high costs. Sometimes flexible plastic pipes with protection for oxygen diffusion may be used.

Prices for pipelines in the secondary distribution net are nowadays:

| | **Single insulation** | **Double insulation** |
|---|---|---|
| DN 20 | 136 | 154 |
| DN 32 | 246 | 262 |
| DN 40 | 256 | 272 |
| DN 50 | 302 | 322 |
| DN 65 | 366 | 390 |
| DN 80 | 410 | 434 |
| DN 100 | 470 | 516 |
| DN 125 | 646 | 690 |
| DN 150 | 1,204 | 1,268 |
| DN 200 | 1,986 | 2,082 |

## 10.5 Piping requirements according to density of population

The size of the pipelines depends to a large extend on the building density. The building density is low where single one family houses, semi-detached houses, bungalows and ribbon building, is combined with utility building as schools. The grids will require 2 to 5 times more pipe than medium density areas.

Medium density areas combine low-rise one-family houses with gardens in front and back with shops, schools and offices. The costs of distribution grids after the substation in medium density areas are NLG 2,400 to NLG 2,700 per housing unit.

In a relatively even division of areas the costs of a transport pipeline amount NLG 600 to NLG 800 per housing equivalent. High density building like high-rise apartment blocks, offices and malls hardly need a distribution net. The consumers may be connected directly. The size of the transport pipelines equals the ones for middle density areas.

## 10.6 Establishing heat losses

District heating pipelines transfer heat to their surroundings. The higher the temperatures, the more heat gets lost. The losses in dug in pipelines may be calculated with information handed out by pipe manufacturers, the soil condition, the applicable temperatures and the flow. This last factor is negligible as long as there is a flow. Practice learned that sound knowledge of the pipelines, the insulation used, materials and thicknesses, and its direct vicinity the existing formulas lead to results that fit the actual findings. These findings are measured during zero-consumption at night. Heat loss is the basic load of the district heating system which varies with outside temperature, supply and return temperatures.

### 10.7 Heat demand through continuous flow

If the controls of heat exchangers for hot tap water disfunction, a small "leakage" may pass the control valve. The resulting heat demand may partly compensate for heat losses. It will also result in too much too warm a return flow which leads to a higher heat loss in return pipelines. The real heat demand and the real heat loss should be known to check whether undefined heat losses occur.

### 10.8 Thermostatic return-temperature controls

There are several reasons why the choice has been made in the district heating project Purmerend for a regime of 90 °C supply temperature and a 50 °C return temperature (90/50 system). At this temperature the overall efficiency is at its best. The cooling down depends totally on the heat consumption by the users. That is no problem in spring and fall because a low supply temperature is the option.

Especially in winter it is a problem. The district heating discussions have not paid sufficient attention to this problem. The simplest way to regulate heat consumption is to prescribe the capacity of the heating elements to assure an acceptable return temperature. This also requires control of the supply flow to the heating elements. A way to control this would be preset valves to optimize flow at a predetermined situation with constant pressure, supply temperature and demand.
Such a system would be inflexible.

It is preferable to install a control valve to all heating elements limiting the return temperature. There are thermostatic valves in the market which do just that. These limiters may be installed on each heating element or centrally in the house installation. The centrally placed temperature limiter may only be installed if all heating elements are well tuned or if there is a circulating pump in the house heating system to correct deficiencies by repeated flow.

# 11. Cost analyses system options

## 11.1 Introduction

For new district heating schemes it is important to know as much as possible of the future developments. The technical hydraulic structure is the backbone for supplying heat to consumers.

For a balanced development of the supply side, distribution grid and costs for running the system, in relation to the demand side, the number of consuming connections to the system, clearly stated environmental and town-planning policies are necessary. Policies need to formulate boundaries in geographical and time dimensions for building activities.

## 11.2 Technical weighing factors

In order to make the right choice of transport- or distribution systems it is required to include all factors playing a role.
Most important factors are:

- the choice of temperature regime determines to a large extend the applicable cost of heat; the higher the supply temperature from CHPS, the lower the power production; the lower the supply temperature, the higher the power production;
- low supply temperatures make heat exchangers superfluous, thus simplified controls and simple substations;
- high supply temperatures reduce the quantity of water to be transported;
- cooling down to a high degree reduces the quantity of water to be transported;
- high initial pressures require smaller pipelines, but require costlier pumps and more pump energy; naturally, the opposite goes for lower initial pressure;
- the application of booster pumps may reduce as well pressure as pipe sizes;
- heat storage tanks could improve power generating efficiency by enabling the CHPS to run at optimal capacity; furthermore storage tanks may be used to allow for peak demand over and above the optimal heat capacity of the CHPS;
- centrally located storage tanks have the advantage of simplicity in operation, but the disadvantage of higher loads in the transport pipelines; the opposite goes for geographical spread of storage tanks;
- domestic hot water may be heated in smaller substations, or per connection whereby substations may serve large areas. Centrally heated domestic hot water requires an extra grid; the distribution pipelines to supply space heating could be marginally smaller. Heat losses of the distribution pipelines could be reduced if supply can be cut off in summer;
- environmental conditions and the cost of heat determine acceptable heat losses, and thus the cost of insulation.

It will be clear that the quality of a cost analysis depends on the number of items taken into consideration.

## 11.3 Technical planning

When starting a new heating scheme, or part thereof, it is all-important to know as much as possible of future developments. Even then it is necessary to build in the possibility for change from the very beginning, e.g. a connecting branch may be started as one leg but it should be changeable to close it in a loop in the future. Clusters may initially be heated directly, controlled as one major connection. In a later stage clusters could be combined within a substation. Therefor space for further developments should be reserved in substations and pump houses.
Extensions brought to light only after a heating system was obviously completed require full insight into the management of the hydraulics involved. Continuous computation of all elements will provide the options to enlarge a systems' capacity at minimal cost. A geographical spread of heat storage tanks often works wonders.

Actually in a bind it will always be sound practice to temporarily accept the fact that peak demand may cause absolute peak loads. Loads that would not be looked for in initial layout. Long practice and the aforementioned continuous computation will make the effects of peak demand foreseeable.
Accepting less than ideal conditions for short periods heightens the flexibility of an existing network.
Case in point is the change-over from an indirect to a direct system in Purmerend.
By putting in an extra storage tank at the edge of a cluster of users the system could be upgraded from serving 22,000 to serving 30,000 housing equivalents without changing or enlarging the existing transport pipelines.

# 12. Conclusion

As was the case for many a heating system, the project Purmerend was originally designed and partly laid-out in far too grand a fashion allowing for far greater demand, as well per connection (housing-equivalent) as for the entire system (simultaneity), then would be ultimately required.
This made it possible to change the planned indirect system to a direct system. The indirect system started from a 90/70 regime, i.e. 90 °C input into house connections and 70 °C return. This to be realized through transport pipelines wherein water at a temperature of 125 °C would be delivered.

At the time the first part of the system was completed, it became evident that a direct low-temperature heating system was possible, e.g. at a 90/50 regime. This would allow an equal transport capacity in the same pipelines and at the same pump pressures. Costs in layout, maintenance and heat losses would be considerably lower. Also, this regime corresponds well with the implementation within the system of a CHPS at the highest possible electricity generating efficiency.
In addition, direct operation will reduce power required by pumps through upgrading of pump efficiency and consequent reduction of pressure.

The general conclusion drawn means that application of a direct system requires 15 % less capital investment than an indirect system. Additionally, heat losses and maintenance costs will be lower, upkeep and operation will be simplified.

Further reduction of pumping power may be obtained by installing booster pumps. Hereby all required pressure does not need to be supplied at source, giving the opportunity to either reduce pressure or reduce pipe sizes. Optimising of heat supply may be gained by optimal application of auxiliary heat sources and heat storage tanks.

Heat storage tanks have two functions. The first function is that they allow the CHPS to run at full capacity (or not at all) allowing for optimal efficiency. Additionally, this will reduce the number of starts, especially in summertime whereby the plant may only be required to run once every two or three days.
The second function is that storage tanks may deliver heat at times of peak demand, thus reducing the maximum size of heat source required.

The obtainable savings in relation to the cost of installing heat storage tanks is so dramatic that consideration will be limited to optimisation. To increase the effect to its maximum, tanks should be situated where their capacity meets demand.

An autonomous control system was designed, incorporating the entire system. When the CHPS produces heat, transport pumps will take hot water out of the storage tank into which the CHPS delivers, and deliver hot water to the transport grid at a pressure of maximum 6 bar. The water level of the storage tank nearest to the CHPS is controlled by a control valve, all other storage tanks by flow balancing. Control of storage tanks and auxiliary boilers is autonomous. All sorts of situations may occur, depending on conditions in the grid.
The controls automatically take care of heat storage. Pumps are directed by a compilation of signals found in the grid, pumps located at the CHPS and at the ABH have key-functions.

By use of telecommunication and a central computer, control may be gained by means of altering parameters of the autonomous controls and reactivating local control systems.
Through conditioned parameters, storage tanks may be switched on or off by means of altering values intended for automatic functioning.
Pressure rising, and thus the outgoing flow to the grid, may be changed by altering the relating factor.

By this a state of the art district heating system was designed, implemented and managed for the municipality of Pumerend, the Netherlands.

# IEA District Heating and Cooling

## Managing
## a hydraulic system
## in district heating

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