Memo

Deltares
Enabling Delta Life

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Onderwerp
Memo Ramplaankwartier

In this memo, the process followed for the design of the low-temperature district heating network at Ramplaankwartier is described. The design considerations are summarized and the results of the hydraulic calculations for the pipeline diameter definition are presented. Finally, the total heat losses of the system and the energy needs of the ATES system’s pumps are provided.

1 System description

In the following sections, a proposed design for a Low-Temperature District Heating network for Ramplaankwartier in Haarlem is described. This study focuses on the preliminary/ concept design of the network, therefore detailed design considerations are not accounted for.

The first step of designing the LTDH network is to define the most cost-efficient tracé of the pipeline system.

The neighbourhood is separated into 4 subareas, each of them is connected to a heat exchanger. The heat exchanger is subsequently connected to the high and low temperature wells of the ATES system. For more details on the sizing and storage capacity and design considerations of the ATES system (see section 5).

Figure 1.1 Sub-areas splitting Ramplaankwartier

The network consists of two parallel installed grids, one of low (7 – 11 ºC) and one of high-temperature (14 – 18ºC). A hydraulically favourable “tree” network layout has been selected for the design. That leads to shorter total pipeline lengths and hydraulically more favourable configuration. Loops may be included for reliability reasons in the detailed design phase.
The warm and cold grids are connected by Heat Exchangers and pumps at the ATES locations and at all house connections. All pumps are installed in a Wheatstone bridge configuration to enable flow in both directions. The ATES groundwater system is separated from the grid and the heat transfer occurs with the help of a heat exchanger. At every house connection a heat exchanger separates the entire consumer installation from the grid.

Initially, a comparison has been performed between the total lengths of a double and a single network in the streets. The first will consist of 4 parallel pipelines and the second of 2 parallel pipelines per street cross-section. A double network solution (4 parallel pipelines per cross-section) has the advantage of shorter house connection lengths as well as minimizing the traffic disturbance during installation since all pipelines will be placed in the sidewalks. However, such a solution would not reduce material costs and at the same time, it will significantly increase the installation costs due to doubling of the trenches' length. Moreover, most roads of Ramplaankwartier are covered with bricks and thus the expensive and time-consuming breaking of the asphalt can be avoided. That makes the single network (2 pipelines per street cross section) a cheaper solution.

Figure 1.2 District heating network Ramplaankwartier (the red stars represent the location of the heat exchangers)

Every house connection functions as a 'prosumer' (producer and consumer) at this network (more details on the operation and design guidelines of LTDH networks are provided in Ref. [3]). Warm water is pumped from the low-temperature ATES during cold winter days and rejected back to cool return lines in the grid. The opposite process is followed in summer when the PVT-panels produce more heat than required by the dwelling. The excess heat production per house warms up the cold water from the cold lines and returns it back to the warm lines of the Low-temperature grid. Eventually, the excess heat is stored in the ATES system. Every individual house connection has a water-water heat pump that is boosting the temperature from the extracted water to the required temperature in order to satisfy the housing heat demands. The operating COP of the housing heat pumps depends on the temperature of the water pumped from the grid.

The 4 subnetworks in Ramplaankwartier should be interconnected to ensure operation during maintenance or in case of damage of any of the subnetwork components.

The time-series of the house demand and supply of thermal energy from and towards the grid are the output of the Polysun model, as performed by TU Delft (S. Mohammadi, personal communication, October 25, 2019).

2 Diameter definition

After determining the network configuration, the next step for the network design is defining the pipeline diameters. The hydraulic software of Deltares WANDA is used for this analysis. Based on past experience of the consortium, the practical minimum external pipeline diameter for the connection lines is 25mm. Smaller diameters are fragile and susceptible to external accidental loads such as rupture due to excavation activities in the proximity of the network.

2.1 Available pipe sizes

For the diameter selection, the commercially available pipelines are presented in Figure 2.1:

Standaard buis afmetingen HDPE en Polypropeen en de bijbehorende SDR getallen en wanddikte;

Uitwendige maat	HDPE/PP wanddikte SDR 7,4	HDPE/PP wanddikte SDR 11	HDPE/PP wanddikte SDR 17	PE 80 wanddikte SDR 17,6	HDPE/PP wanddikte SDR 26	HDPE/PP wanddikte SDR 33	HDPE/PP wanddikte SDR 41
12		1,8					
16	2,2	1,8					
20	2,8	1,9		1,6			
25	3,5	2,3	1,8	1,6			
32	4,4	2,9	1,9	1,9			
40	5,5	3,7	2,4	2,3	1,8		
50	6,9	4,6	3,0	2,9	2,0		
63	8,6	5,8	3,8	3,6	2,5	2.0	
75	10,3	6,8	4,5	4,3	2,9	2,3	1.9
90	12,3	8,2	5,4	5,1	3,5	2,8	2,2
110	15,1	10	6,6	6,3	4,2	3,4	2,7
125	17,1	11,4	7,4	7,1	4,8	3,9	3,1
140	19,2	12,7	8,3	8	5,4	4,3	3,5
160	21,9	14,6	9,5	9,1	6,2	4,9	4
180	24,6	16,4	10,7	10,2	6,9	5,5	4,4
200	27,4	18,2	11,9	11,4	7,7	6,2	4,9
225	34,2	20,5	13,4	12,8	8,6	6,9	5,5
250	38,3	22,7	14,8	14,2	9,6	7,7	6,2
280	43,1	25,4	16,6	15,9	10,7	8,6	6,9
315	48,5	28,6	18,7	17,9	12,1	9,7	7,7
355	54,7	32,2	21,1	20,1	13,6	10,9	8,7
400	61,5	36,3	23,7	22,7	15,3	12,3	9,8
450		40,9	26,7	25,5	17,2	13,8	11
500		45,4	29,7	28,3	19,1	15,3	12,3

Relatie SDR en drukklasse:
HDPE 80 SDR 11 PN10
HDPE 100 SDR17 PN10
HDPE 100 SDR11 PN16

Figure 2.1Commercially available pipeline diameters and wall thicknesses for HDPE[1]

For this project, an SDR 11 pipe class has been selected.

[1] Data from Lever Kunststoftechniek and Thermaflex.

2.2 Network layout

A common design practise for district heating networks is to define the diameter based on a maximum allowable pressure drop per meter length of pipeline network. For district heating networks a typical applied rule of thumb is that the maximum allowable pressure drop per meter pipe length should not exceed the value of 300 Pa/m (Ref. [1]). Alternatively, another often reported design consideration is that flow velocity should not exceed the value of 2m/s. The pipeline roughness factor is chosen as 0.5mm in order to include sufficient allowance for the additional local losses due to pipe fittings, isolation valves and T-pieces.

The design is performed for the maximum discharge from the houses towards the system during a warm summer day. A maximum power of 6kW per house is considered and a temperature difference of 7°C (heating up the cold water in the house installation from 13°C to 20°C and in the network from 11°C to 18 °C). Simultaneity reduction factor is conservatively not accounted for since all the houses will be delivering the maximum produced heat to the network.

In the Appendix, a sensitivity analysis with a maximum power per house of 8kW is performed and the diameters and network are presented.

The mass flow rate is calculated as presented below:

$$\dot{m} = \frac{Q_{\max} * 3600}{c_n * \Delta T}$$

Where:
Q_{max} is the maximum design power in [W], c_n is the volumetric heat capacity of water (4200.0 kJ/m3/C) and ΔT is the temperature difference of 7°C.

Every design node requires a mass flow rate of 736.62 kg/hr or approximately a discharge of 0.736 m^3/hr.

Multiple steady-state simulations are carried out, changing the pipeline's diameter in an iterative manner until the calculated pressure drop satisfies the design principle of 300Pa/m. Subsequently, the calculated diameters are rounded up to the nearest commercially available diameter and the smaller connection lines are rounded up to the minimum outer diameter of 25mm.

Based on the hydraulic calculations performed as described above, the length per pipeline diameter is summarized in Table 2.1. These values correspond to the warm lines only thus they should be doubled in order to account both warm and cold lines in the grid. The corresponding GIS shapefiles are provided as an attachment at this document for future reference and added to the appendix section of this report (Section 7).

Table 2.1 Pipeline length per diameter for a supply of 6kW per house connection

Nominal Diameter	East	North	South	West

[mm]	[m]	[m]	[m]	[m]
25	3622.8	3276.7	3428.1	5970.9
40	134.4	146.9	54.9	120.8
50	251.5	176.5	67.3	123.7
63	178.1	430.6	202.2	228.4
75	189.9	210.4	86.6	194.1
90	312.0	97.3	160.5	253.9
110	398.4	136.8	146.7	251.4
125	160.2	116.3	127.7	157.0
140	51.9	83.2	165.9	34.7
160	103.4	104.6	186.7	139.4
180	12.5	-	21.3	225.4
200	-	24.2	10.7	31.1
225	6.8	143.3	-	25.1
250	-	-	-	32.1

The material and installation costs are presented in Ref [4].

After the diameters have been defined, Wanda steady state simulations are performed to calculate the pressures in the network. In Figure 2.2 the pressures with the diameters of Table 2.1 are presented. The maximum differential pressure in this design condition in the warm line is 1.1 bar. Hence the design pump head for the house pumps is 2.3 bar (230 kPa), including 0.1 bar for the heat exchanger.

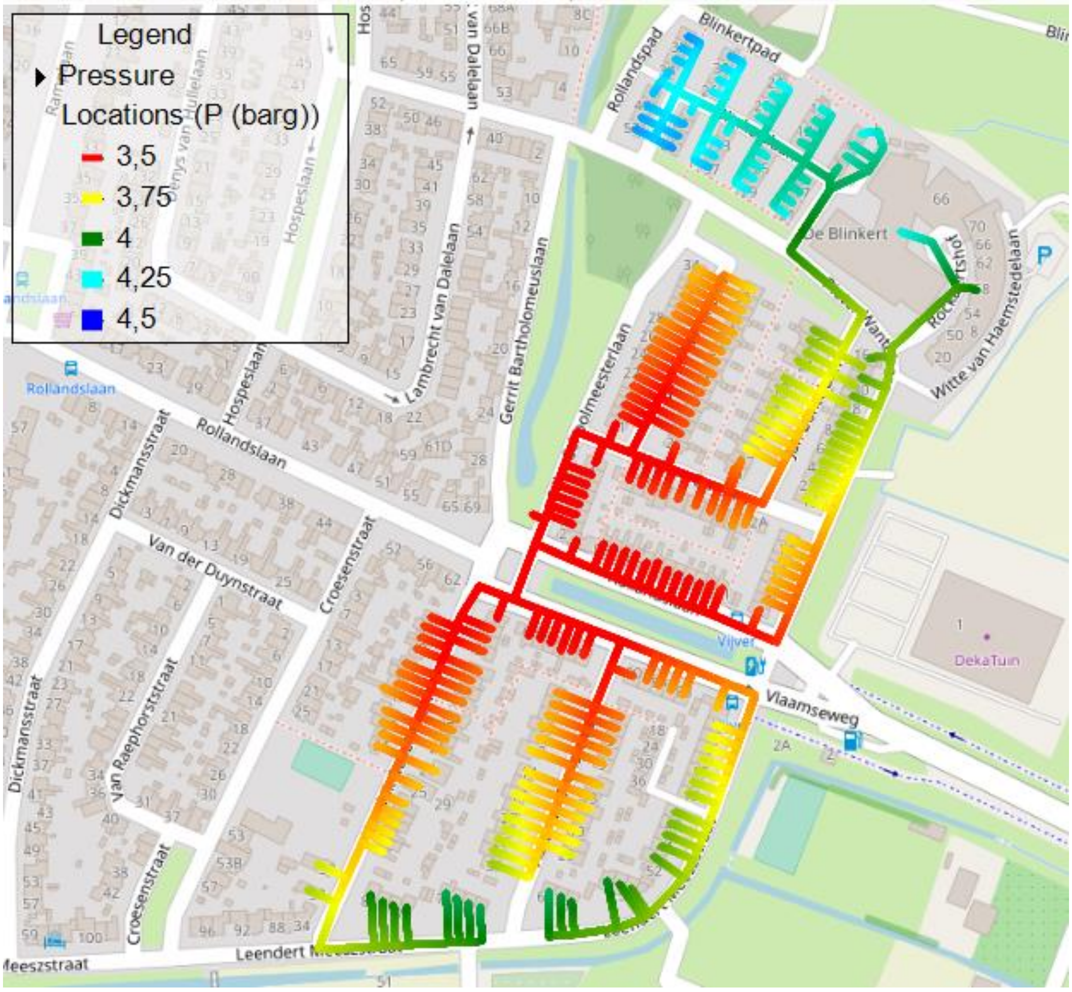

Figure 2.2 Pressure graphs during discharging from nodes towards the ATES house connection 6kW.

Based on these maximum pump heads, the recommended equilibrium pressure in the warm and cold lines near the ATES heat exchanger is 3 to 4 barg, to ensure steady state pressures well below 6 barg and above 1,5 barg; an equilibrium pressure of 3.5 barg was used in Figure 2.2. This equilibrium pressure is the control variable for the pump on the grid side of the ATES Heat exchanger.

2.3 Conclusion and recommendation on network diameters

It is recommended to re-perform these design calculations in the detailed design phase when more detailed information on the level of participation becomes available, especially the non-residential dwellings (Shopping centre). Also, the level of reliability needs to be addressed in the detailed design phase.

3 Heat losses

3.1 Heat capacity of water and conduction factors of materials

The heat capacity of the water is assumed constant and equal to: 4200 J/kg K.

In order to estimate the heat losses of the system the following conduction factors are considered:

Table 3.1 Material Conductivities

Material	**Conductivity**
[-]	[W/m*K]
HDPE	1.4
PUR	0.03
Soil	1.6

These values are assumed to be time constant in the heat losses calculation model.

Two different scenarios are accounted for and compared. One with and one without insulation layer. The insulation material is PUR (Polyurethane foam) and the diameter of the outer layer is presented at the table below:

DN maat

ø nom.	Outer casing ø out. mm	Outer casing Wall thick. mm
20	110	3.0
25	110	3.0
32	125	3.0
40	125	3.0
50	140	3.0
65	160	3.0
80	180	3.0
100	225	3.4
125	250	3.6
150	280	3.9
200	355	4.5
250	450	5.2
300	500	5.6
350	560	5.7
400	630	6.0
450	710	6.6
500	800	7.2
600	900	7.9

Figure 3.1 Polyurethane foam outer diameters (https://www.leverkunststoftechniek.nl/abc-register/o/ontwerp-kunststof-leidingen/sdr-waarde/ https://www.leverkunststoftechniek.nl/abc-register/o/ontwerp-kunststof-leidingen/bestek-tekst-hdpe-pe-hd-druk-in-pn-2/)

3.2 Heat loss calculation

The heat losses of the system are calculated with a simple analytical model:

The heat transfer coefficient of the pipe in a radial system is calculated with:

$$h = \frac{2 * \lambda}{D_2 \, ln \frac{D_2}{D_1}}$$

Where D_2, D_1 is the outer and the inner diameter of each layer (HDPE, PUR, soil) respectively and lambda is the heat conductivity of each layer.

$$Q = L\,(U_1 - U_2)(T_1 - T_g) + LU_2(T_1 - T_2)$$

The heat loss coefficient of the pipe is calculated with the following equation:

$$U_1 = \frac{R_{ground} + R_{iso}}{(R_{ground} + R_{iso})^2 - R_m^2}$$

Where R_{ground}, R_{iso} and R_m are the heat resistance of the ground, isolation and pipe material respectively.

T_1 is the temperature of the pipe, T_g is the ground temperature and T_2 is the temperature of a parallel installed pipeline in the ground. U_2 is the heat loss coefficient due to the interaction between 2 pipelines. For simplicity, U_2 has been assumed zero at this stage.

The above described methodology is as per NEN specification Ref [5].

The ambient temperature that is accounted for in the heat loss calculations is:

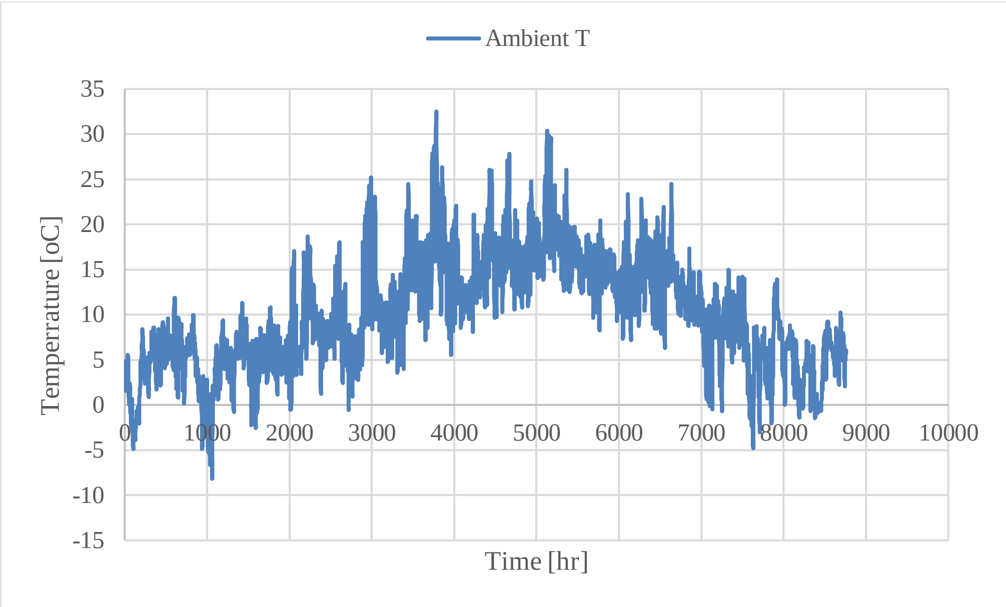

Figure 3.2 Ambient Temperature [°C] (TU Delft S. Mohammadi, personal communication, April 16, 2019)

This simplified approach is compared with the results of a daily simulation with Deltares software Wanda Heat. The main difference between these approaches is that Wanda heat accounts for the internal temperature evolution along every pipe element whilst for the simplified model the temperature of the grids is constant, which results in a conservative estimate of the heat loss.

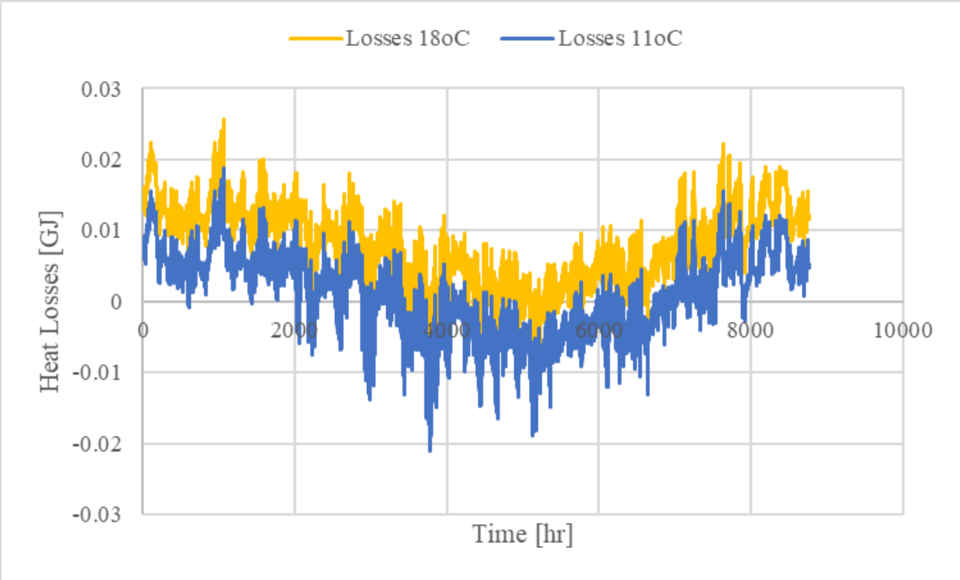

Figure 3.3 Hourly heat losses for 18 and 11 °C pipeline network (PUR coated pipelines).

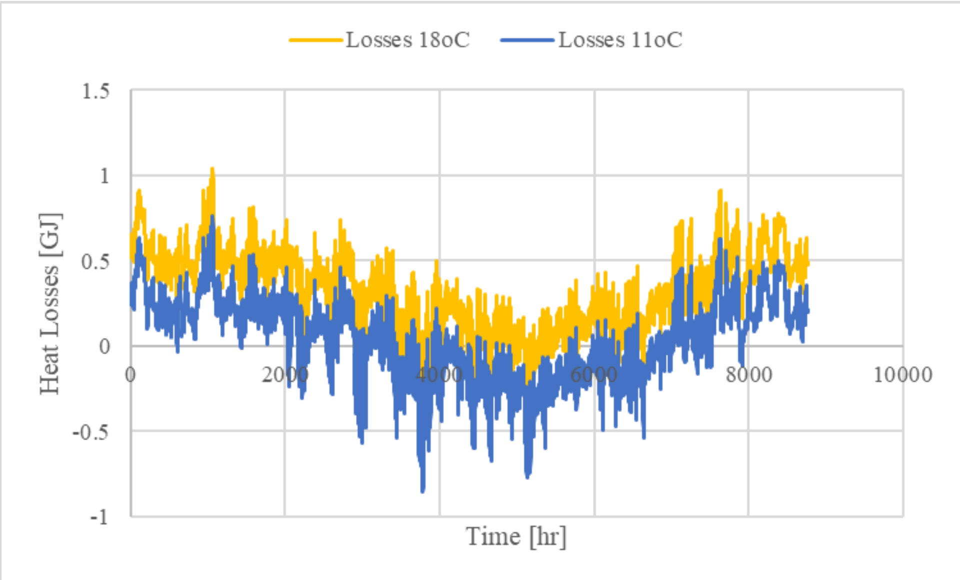

Figure 3.4 Hourly heat losses for 18 and 11 °C pipelines(uninsulated pipelines).

In order to relate the heat losses to the total heat demand, assumptions are required on the annual heat demand per household; the house type and heat demand variability have been used. The different house types depending on the roof orientation and the number of floors have been provided by Building technology TU Delft (S. Mohammadi, personal communication, October 25, 2019).

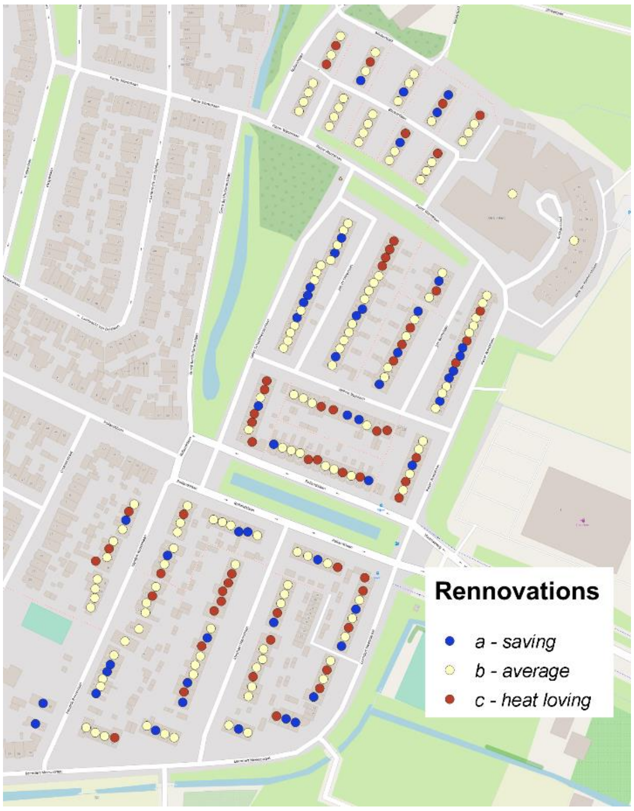

Figure 3.5 House Rennovations Ramplaankwartier East.

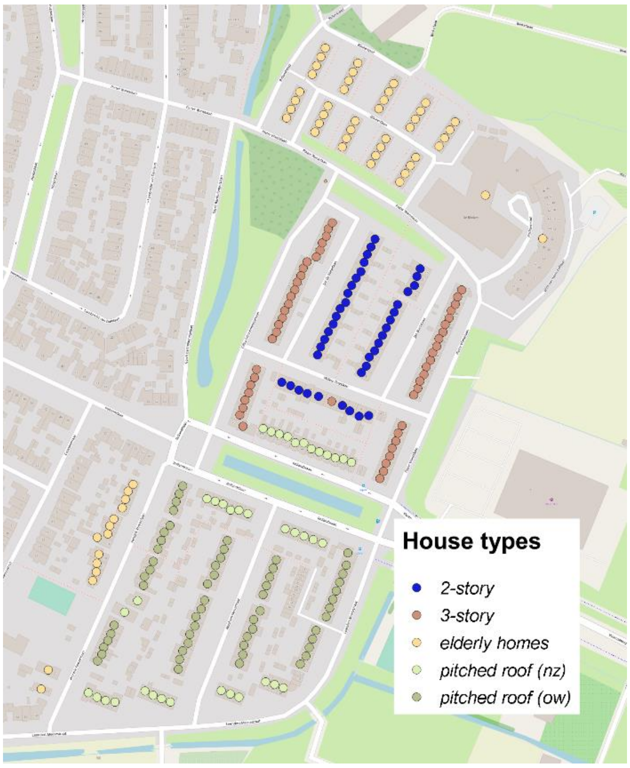

Figure 3.6 House types Ramplaankwartier East (S. Mohammadi (personal communication, October 25, 2019)

The renovation status of the houses was not available during this project, therefore an approximated ratio of 50% average, 25% heat-loving and 25% energy-saving houses are considered. In Figure 3.5 and Figure 3.6 the renovations and house type are depicted. A significant fraction of the total heat demand is supplied directly from the PVT panels. The building simulations (ref. Mohammadi) indicate that an average of 15 GJ/household must be extracted from the ATES-grid, resulting in the percentual heat losses in Table 3.2.

Table 3.2 Heat losses /year/ house.

Area	Heat losses: Warm lines	Heat losses: Cold lines	Total losses	Number of houses	Heat losses for year/ house	% of total energy
	[GJ / year]	[GJ / year]	[GJ / year]	[-]	[GJ /year house]	[%]
Ramplaankwartier East with PUR insulation.	206	25	231	243	0.95	5.8
Ramplaankwartier East without insulation.	2784	340	3124	243	12.9	46

As it can be concluded form the Table 3.2 the heat losses for uninsulated pipes compose 46% of the total energy production via the grid. Therefore, even though such an option will have lower investment costs it will be energetically unfavourable compared to the insulated pipes. Compared to a traditional district heating network, a prosumer network can satisfy a part of its demands when operating in stand-alone mode. During the timespan that each dwelling can satisfy each own heat needs without using the grid, there are no losses in the network but also no demand. The total losses in absolute values per year are, as expected significantly lower, than the typical heat losses in conventional district heating systems.

3.3 Cross checks to heat loss calculation

The magnitude of this heat loss calculation is verified in three ways. First an internal consistency check. The ratio of the uninsulated network heat losses and the insulated network heat losses is 13.5 (= 3124 / 231). This value is equal to a weighted average of the ratio of heat loss coefficients U1 for uninsulated pipes and insulated pipes. These U1-ratios vary from 15.6 in DN25 lines to 9,5 in DN160 lines.

A second verification is a comparison with supplier specs for low-temperature grids that provide an average heat loss in W/m for different pipe sizes (Table 3.3).

Table 3.3 Heat losses for different supply temperatures and pipe sizes (adapted from Thermaflex)

DN	160	125	110	90	75	63	50	40	32	25
Heat loss 70 supply (W/m)	18.1	17.0	14.0	13.3	15.3	14.7	13.7	10.3	11.5	8.8
Heat loss 50 supply (W/m)	13.1	12.6	10.4	9.9	11.3	11.2	10.6	8.0	8.9	7.0
Heat loss 30 supply (W/m)	10.2	8.3	6.9	6.5	7.4	4.4	4.4	3.4	3.8	3.0

The (linear) weighted average heat loss, based on pipe lengths, equals 4.15 W/m for a supply temperature of 30 °C. Assuming a seasonal background temperature of 10 °C, this heat loss reduces to 1.66 W/m for a supply temperature of 18 °C.

The overall heat loss for the insulated pipes in Ramplaankwartier Oost of 231 GJ, corresponds to an average of 1.35 W/m, which is 20% smaller than the data from Thermaflex would suggest. This is a reasonable ratio given the simplified approach and the fact that suppliers may need to guarantee at most the specified heat loss.

As and additional verification, an analysis with a steady-state Wanda Heat model with a constant ambient temperature has been used to compare the results of the simplified analytical model. The pipeline temperatures are kept constant along the pipeline.

The comparison of these two methods is provided in the table below:

Scenario	Temperature	Simplified	Wanda	Difference
		[W / m]	[W / m]	[%]
Insulated	18^{o}C	1.206	1.186	1.61
	11^{o}C	0.147	0.148	-0.63
Uninsulated	18^{o}C	16.28	15.08	7.36
	11^{o}C	1.99	1.88	5.68

3.4 Conclusion on required level of insulation

The insulated network results in acceptable heat losses of less than 1 GJ/house/yr, based on the conservative assumption of high summer temperatures (18/11^{o}C) in the LT-grid.

The uninsulated network results in excessive heat losses from the grid (13 GJ/house/yr). All buildings would need 30% to 50% more PVT panels to compensate for this heat loss to the surroundings, which is not feasible. From a energetic point of view, the grid should be insulated.

It is noted that the warm lines are responsible for the heat losses in the uninsulated network. In reality the expected temperature in the cold lines, which ranges from 11 ^{o}C in summer to 7^{o}C in winter, stays fairly close to the ambient temperature at -1m. Therefore, an economic alternative might be to insulate the warm lines only. It is recommended to evaluate the following scenarios in the business case:

1. Fully insulated network with twin pipe for smaller diameters.
2. Insulated twin pipes for house connections (possibly smallest distribution lines), insulated warm lines in the remainder of the grid and uninsulated cold lines in the remainder of the grid.

4 Pump energy calculation

4.1 Hydraulic losses per Heat exchanger at every house location

Based on the specification of the heat exchangers the hydraulic resistance at every heat exchanger is calculated as follows:

		F - Side		P - Side
DUTY REQUIREMENTS		**Side 1**		**Side 2**
Fluid		**Water**		**Ethylene Glycol - Water (33,0 mass%)**
Flow type			**Counter-Current**	
Circuit		Inner		Outer
Heat load	kW		**6,000**	
Inlet temperature	°C	**15,00**		**5,00**
Outlet temperature	°C	**7,00**		**13,00**
Flow rate	kg/s	0,1789		0,2105
Pressure drop (Design PD)	kPa	7,22 **(11,00)**		9,94 **(11,00)**
Thermal length		4,000		4,000
PLATE HEAT EXCHANGER		**Side 1**		**Side 2**
Total heat transfer area	m²		1,32	
Heat flux	kW/m²		4,55	
Mean temperature difference	K		2,00	
O.H.T.C. (available/required)	W/m²,°C		2320/2270	
Pressure drop - total*	kPa	7,22		9,94
• in ports	kPa	0,0629		0,0824
Number of channels per pass		11		12
Number of plates			24	
Oversurfacing	%		0	
Fouling factor	m²,°C/kW		0,008	
Reynolds number		226,7		90,77
Port velocity (up/down)	m/s	0,365/0,365		0,407/0,407
Channel velocity	m/s	0,0993		0,102
Shear stress	Pa	11,0		15,2
Average wall temperature	°C	10,25		10,19
Largest wall temperature difference	K		0,14	
Minimal/Maximal wall temperature	°C	6,28/14,28		6,14/14,14
**Excluding pressure drop in connections.*				
PHYSICAL PROPERTIES		**Side 1**		**Side 2**
Reference temperature	°C	11,00		9,00
Dynamic viscosity	cP	1,27		3,42

Figure 4.1 House heat exchanger specification (Ref Single phase Heat exchanger SWEP specification document)

For a mass flow rate of 0.2105 kg/s (corresponding to 0.000211 m^3/s), the pressure drop at the heat exchanges is 9.94 kPa (1.17 m). The hydraulic resistance is calculated as follows:

$$DH = c * Q^2$$

The resistance value is calculated with the above formula: C = 22840212 (s^2/m^5) at the location of the heat exchanger of every house.

The pressure loss of the large heat exchanger, directly connected with the ATES wells, is 0.5 bar.

The total energy of the pumping station is the summation of all the hydraulic losses in the network, the losses at the locations of the heat exchangers at every connected house and the losses at the large heat exchanger of the ATES.

$$\Delta P_{HE} = \Delta P_{HE\_ATES} + \Delta P_{House}$$

$$Energy\ loss\ HE = \Delta P_{HE\_ATES} * Q_{ATES} + \Delta P_{House} * Q_{ATES}$$

4.2 Hydraulic losses at the pipeline network

In order to calculate the energy losses in the network a steady state Wanda Heat simulation has been performed. The summation of all generated heat flux due to friction at all the pipeline elements represents the friction energy loss in the system.

4.3 Pump energy

The total energy loss that the pump should compensate for is the summation of the energy loss at the heat exchangers and the hydraulic losses in the pipeline system for Ramplaankwartier East subsegment.

The total hydraulic energy for every house heat exchanger:

$$E = \int \Delta P * Q * dt = \int c * Q^3 * \rho * g * dt$$

See section 4.1 for the explanation of the c value.

For the ATES heat exchanger, the pressure drop is estimated as follows:

$$\Delta P = max\left\{50(kPa) * \left(\frac{Q_t}{Q_{max}}\right)^2, 30(kPa)\right\}$$

This minimum value of pressure drop at the ATES heat exchanger is applied to ensure that the flow velocities (Reynolds, and Nusselt numbers) in the heat exchanger are high enough for the heat convection to take place.

$$E = \int \Delta P * Q * dt$$

The friction losses are calculated for both pipelines for the maximum expected discharge of 175m^3/s. The maximum generated power due to friction in the system for this discharge is: 5.74kW.

$$P_{max} = \Delta P * Q_{max} = a * Q_{max} * Q_{max}$$

From this equation the α is back calculated and subsequently used for the power calculation due to friction depending on the changing discharges in the pipeline system.

This α value is thus:

$$\alpha = \frac{5.74}{(175/3600)^2} = 2429.1\ (kW.s^2/m^6)$$

Table 4.1 Hydraulic energy losses at design capacity (6 kW/household)

Component	Power losses
[-]	[kW]
ATES Heat exchanger	50
House Heat exchanger	0.41
Hydraulic losses in the network (double line)	2 * 2.87= 5.74
Total hydraulic losses	55.94

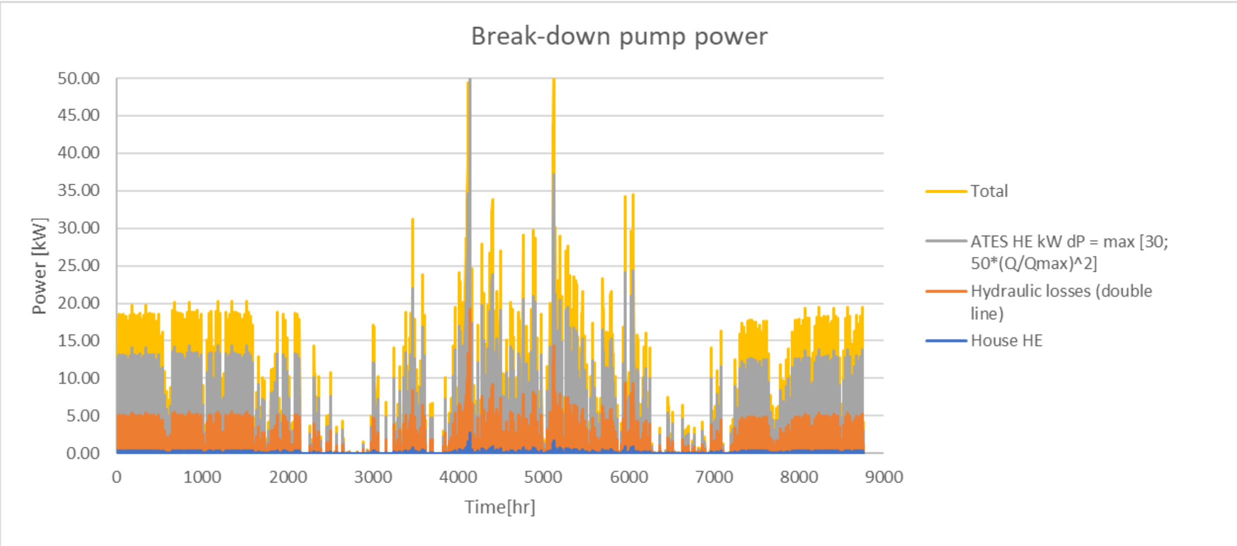

Figure 4.2 Total hydraulic energy per year.

Table 4.2 yearly cumulative energy

Component	Net pump energy
[-]	[kWh]
ATES Heat exchanger	12749.3
House Heat exchanger	283.4
Hydraulic losses in the network (double line)	4890.6
Total net pump energy	17923.4

On the above presented losses, the pump efficiency reduction due to the pump impeller and motor are accounted for as 0.7 and 0.8 respectively.

Summarizing the described methodology and the values presented in Table 4.2, the total net pump energy in the system is 17.9 MWh, equivalent to 64.5 GJ. Taking the pump and motor efficiency into account, the required pump energy equals 102 GJ

$$Total\ energy = \frac{64.5\ [GJ]}{0.7\ * 0.8} = 102.4\ [GJ]$$

The coefficient of performance of the pump is:

$$COP = \frac{7719.7\ [GJ]}{102.4\ [GJ]} = 75.37$$

4.4 Pump selection

The methodology provided is an approximation of the total energy that should be added to the system. For the selection of all the system pumps, the pressure and discharge should be attributed to each component.

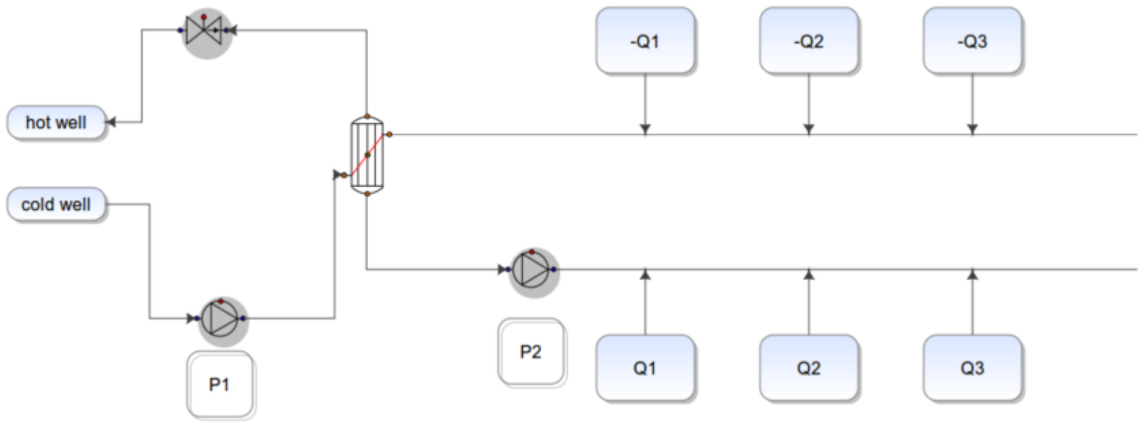

Figure 4.3 Street configuration

The system is equipped with groundwater pumps in the wells and one pump (P2) at the network side of the ATES heat exchanger. Pump P2 is integrated into a Wheatstone configuration so that the flow direction can be inverted.

Control valves in the wells maintain the pressure in this circuit at the degassing pressure of the ground water. For preliminary design phase that can be assumed equal to 2bar at ground level. An additional drawdown of the water table of maximum 5m should be additionally accounted for, resulting in a total 2.5bar control pressure.

Pump P2 on the network side needs to compensate the ATES heat exchanger head loss (50 kPa). The pumps in the dwellings need to compensate for the local heat exchangers and the friction losses in the grid.

The mass flow rate and therefore the discharge at the inner and outer circuit are equal, and the summation of the all the design flow rates at the house connections. For the cluster of Ramplaankwartier East, this is 175m^3/hr.

Property	P1 (groundwater circuit)	P2 (LT circuit)
Pressure [kPa]	250	50
Discharge [m^3/hr]	175	175
Hydraulic power [kW]	19.56	2.45

Every house connection has as well a hydraulic pump that is pumping from one line and reinjecting it back into second one. To estimate the pump energy per house, two mirror hydraulic Wanda models have been made. In one model all the discharge house nodes are pumping water from the system and at the second model they are rejecting to the system. The pressure difference in every node is equal to the pressure per pump house connection. Depending on the distance of the house connection from the heat exchangers, the pressure of the house hydraulic pumps ranges from 28.6kPa to 232kPa for the most remote houses. In Figure 4.4, the pressure of every house pump is depicted.

Figure 4.4 House connection pump pressure

The pump pressure at every house location account also for the additional local losses of each house's heat exchanger (9.4kPa).

5 ATES Ramplaan East

5.1 Location of ATES and network connection

The location of the ATES wells is as described in Ref. [2]. The locations of the heat exchangers are selected in such a way that they are in an open area with available space for their installation. At the same time, they should be as close possible to connected sub-grids.

In Figure 5.1 the locations of the ATES wells and the connecting pipelines from the wells to the heat exchangers are presented.

Figure 5.1 Connection of ATES wells to heat exchangers.

The pipeline connection lengths and diameters are presented in Table 5.1. These lengths should also be accounted in the total network costs in Ref. [4].

Table 5.1 Connecting pipelines ATES wells to Heat exchangers

Outer Diameter	East/North	South	West
[mm]	[m]	[m]	[m]
200	-	151.6	-
225	325.16	-	-
250	-	-	312.66

5.2 ATES storage

In this section, the required storage of the ATES wells of the subsection Ramplaan east is determined.

The total demand consists of the demands for space heating as well as those for hot water. The demand and supply from and towards the system is the output of the performed simulations by Building technology TU Delft, S. Mohammadi (personal communication, October 25, 2019). The house type, roof orientation and renovation status have been accounted for in this analysis (presented in Figure 3.6 and Figure 3.5 respectively).

The yearly energy deficit stems from deducting from the total energy demand, the supply from the PVT panels. This deficit should be stored on a yearly basis in the ATES system and delivered back to the households when required. The aggregated power deficit for all the houses in Ramplaankwartier east is depicted in Figure 5.2:

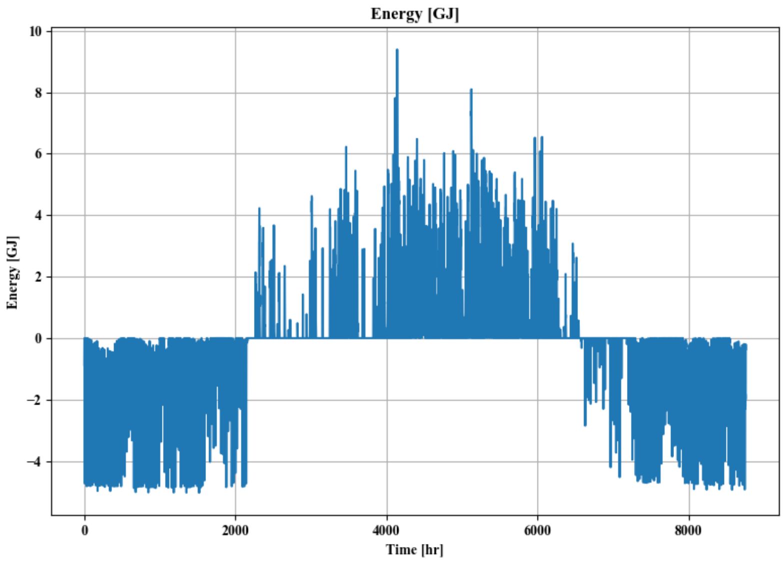

Figure 5.2 Aggregated yearly demands in GJ Ramplaan East (output of Polyson software: S. Mohammadi (personal communication, October 25, 2019)

The negative values correspond to an energy demand from the system during the winter months, whilst the positive value represents the total delivery from the PVT panels to the system.

$$V = \frac{E}{\rho_w c_w \Delta T}$$

Where V is the injected or infiltrated volume of water at an hourly timestep in [m^3], c is the specific heat of water [$J*kg^{-1} * K^{-1}$]; E is the thermal energy demand [J]; ΔT is the temperature difference between the water that is extracted and the temperature with which it re-enters the aquifer.

This thermal energy deficit translated into a water volume deficit on an hourly basis is presented in Figure 5.3:

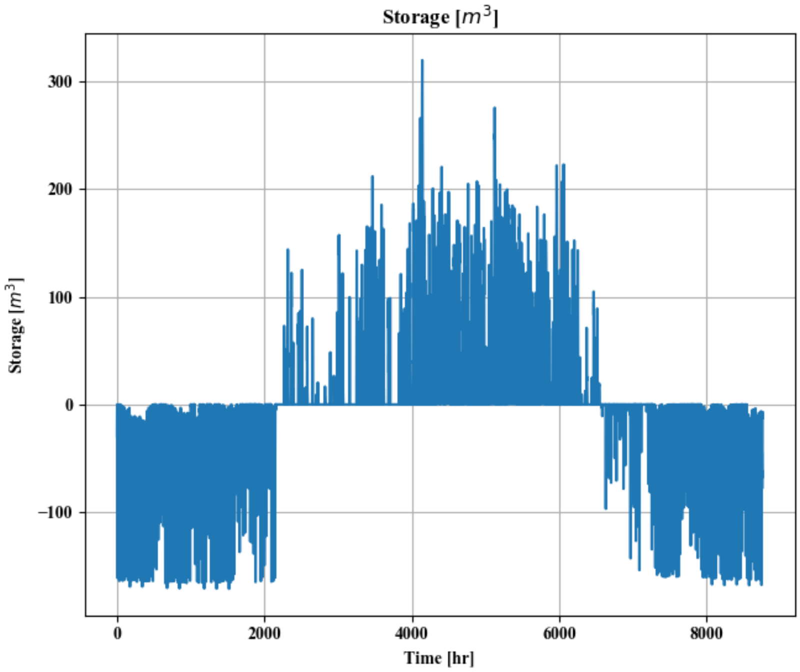

Figure 5.3 Hourly storage in m³ based on the aggregated timeseries in Ramplaan east

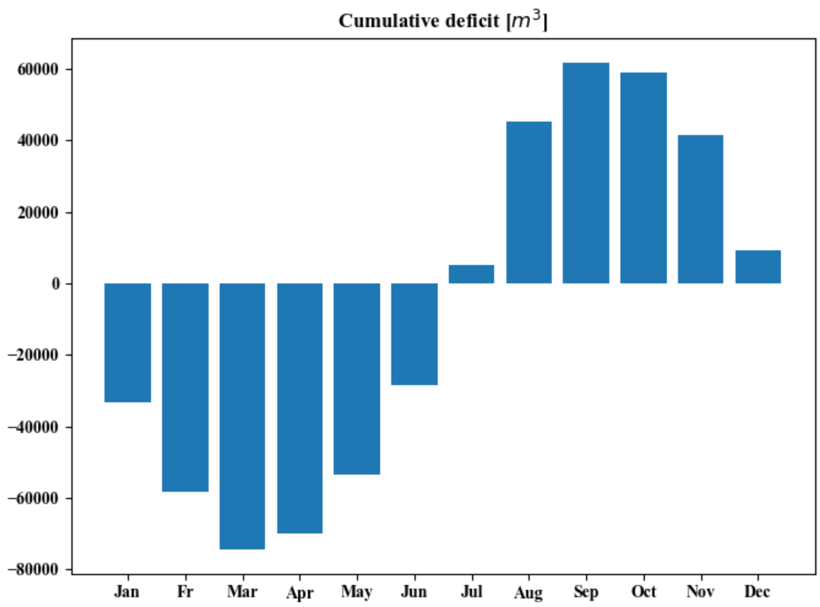

Figure 5.4 Cumulative storage deficit [m³]

The total storage volume of the ATES system is the maximum cumulative demand added to the maximum cumulative supply to the system and equals to: 135964.15m³ (maximum cumulative positive – minimum deficit).

Table 5.2 ATES parameters (storage, thermal diameter and distance) for four scenarios.

	Units	Results
Yearly storage volume of groundwater per ATES	[m^3]	135964.15
Thermal diameter	[m]	Ref. [2]
Optimal distance between opposite type of wells	[m]	Ref. [2]
Optimal distance between same type of wells	[m]	Ref. [2]

6 References

[1] I. Best, J. Orozaliev, K. Vajen. Impact of Different Design Guidelines on the Total Distribution Costs of 4th Generation District Heating Networks;16th International Symposium on District Heating and Cooling, DHC2018; Energy Procedia 2018, Volume 149.
[2] Dr. ir. M.Bloemendal 2019-10TKI-DeZONNET Notitie bronnen bodemenergiesysteem. j.m.bloemendal@tudelft.nl
[3] Design Guideline
[4] Business case (GREENVIS)
[5] NEN-EN 13941+A1, Ontwerp en installatie voor geïsoleerde buissystemen voor stadsverwarming, 2010

7 Appendix

In this section a sensitivity analysis is performed with a house connection of 8kW for the Eastern cluster of Ramplaankwartier. New pipeline diameters are selected with the same process that has been described in paragraph 2.

A new Wanda liquid model is created with a power demand per house of 8kW and a temperature difference of 7°C.

The new mass flow rate for these discharges is calculated as below:

$$\dot{m} = \frac{Q_{\max} * 3600}{c_n * \Delta T}$$

Every design node requires a mass flow rate of 982.64 kg/hr or approximately a discharge of 0.0003 m^3/s (0.9822 m^3/hr).

The calculated diameters with the new mass flow rate per house connection are presented in Table 7.1.

Table 7.1 Comparison network diameters for 6kW and 8kW house connection.

Outer Diameter	East_6kW	East_8kW
[mm]	[m]	[m]
25	3622.8	3622.8
40	134.4	-
50	251.5	269.0
63	178.1	169.2
75	189.9	160.6
90	312.0	215.2
110	398.4	385.5
125	160.2	270.3
140	51.9	154.5
160	103.4	52.0
180	12.5	103.4
200	-	12.5
225	6.8	-
250	-	6.8

The total pump energy for the additional scenario of the 8kW per house connection is summarized in Table 7.2.

Table 7.2 Hydraulic energy losses

Component	Energy losses
[-]	[kWh]
ATES Heat exchanger	3.32 50
House Heat exchanger	-1.1
Hydraulic losses in the network (double line)	2* 6.07 = 12.14
Total hydraulic losses	63.24