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Low temperature district heating based on low temperature geothermal heat (30 ºC)

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Abstract

A comparative study for a representative case district in the Netherlands with around 2500 dwellings has been executed with the purpose of identifying the best solution for a Low Temperature District Heating (LTDH) with Low Temperature Geothermal Heat (LTGH) as the main heat source. The district is presently connected to the Dutch gas network. Its heat demand and building typologies are used as departing points. The comparison is based on 3 key performances indicators (KPI's): CO_2 emissions, levelized costs of energy (LCOE) and peak electricity use. The following LTDH designs have been considered: Central heat pump and collective peak supply at 70 ºC / 50 ºC; Central heat pump and decentral peak supply at 70 ºC / 50 ºC; Decentralized heat pumps using 30 ºC supply temperature. Individual air source heat pumps for space heating and electric boilers for domestic hot water purposes are taken as reference. The LTDH concept with decentralized heat pumps saves 19.5 %, 16.8 % and 36 % on the CO_2 emission, LCOE, and electricity use in peak load hours compared to the reference concept.

Keywords: heat pump; low temperature district heating;low temperature geothermal heat source;

1. Introduction

In 2015, 34% of the total energy use in the Netherlands originated from the built environment. 70% of the energy use in this sector was for heating dwellings, cooking food and the preparation of hot water, while the remaining was for electricity use [15]. With the current climate developments, earthquakes as a result of natural gas extraction in the northern parts of the Netherlands and a transition in public thinking towards making the world more sustainable, an investigation of alternative ways of supplying heat to Dutch dwellings has become increasingly relevant.

According to Kremer et al. [15], in 2015, 78% of the total heating requirement originated from natural gas combustion. In Dutch households, 219 PJ of natural gas was used for heating homes, 60 PJ was used for domestic hot water supply, and 6 PJ for cooking. The Dutch government aims to disconnect Dutch houses from the existing gas distribution network by 2050, and wants to stop natural gas extraction in Groningen by 2022. New solutions are required on short term to deliver the heating requirements. District heating systems, together with heat pumps, are the most commonly suggested solution for replacing the natural gas distribution network in the densely populated urban areas of the Netherlands. Low Temperature District Heating (LTDH) is one of the proposed solutions which is claimed to have high efficiency and to be easy to connect to sustainable heating sources [18].

Nomenclature

Roman characters	*Subscripts*

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A	Area	m^2	ATES	Aquifer thermal storage
COP	Coefficient of performance	-	C	Cold source
c_p	Specific heat	$kJkg^{-1}K^{-1}$	Carnot	2nd law of thermodynamics
F	Fuel costs	€	demand	Demand side
I	Investment costs	€	elec	Electrical
M	Maintenance costs	€	H	Hot sink
$\dot{m}$	Mass flow rate	kgs^{-1}	HP	Heat pump
n	Number of years	-	injection	Injection well
Q	Energy	kWh	loss	Related to heat losses
$\dot{Q}$	Power	kW	LTDH	Low temperature DH
r	Interest rate	-	LTGH	Low temperature GH
T	Temperature	ºC	peak	Peak load conditions
U	Overall heat transfer coefficient	$kWm^{-2}K^{-1}$	recovery	Recovery of ATES
$\dot{W}$	Shaft power	kW	return	Return line
Greek character			supply	Supply line
η	Efficiency	-	well	Production well

Several researchers have investigated the feasibility of the implementation of LTDH in the Netherlands [25, 30, 31]. The results seem promising but the proposed solutions are not capable of delivering the peak duty during cold periods. European studies [18, 21, 23] have however concluded that LTDH would provide a sustainable way of supplying heat to dwellings. Most houses in the Netherlands are equipped with radiators designed for high temperature heat delivery which limit the use of low temperature heating systems. According to Østergaard [20], in Denmark, such radiators are oversized and can still be used in LTDH. This, however, still needs to be confirmed to apply for the Dutch situation.

This study investigates how a low temperature (30 ºC) geothermal source (originating from aquifers in the drilling range between 500 to 1250 m below ground level) can best be used for heating purposes in urban areas by considering a specific area in the Netherlands. The use of such geothermal heat sources for heating of greenhouses has recently been reported by Schepers et al. [25].

Geothermal installations consist of two wells, a production well and an injection well. Hot water is extracted from an aquifer at elevated temperature by the production well. The hot water is pumped from the production well to a heat exchanger (HEX), which may be part of a heat pump, at surface level. The HEX, eventually after temperature upgrading by a heat pump, transfers the heat to a secondary water network. The cooled production water is pumped back into the aquifer via the injection well. The amount of heat, which is extracted by the installation, depends on the mass flow of the ground water and the temperature difference across the HEX. The temperature of the water extracted depends on the depth of the aquifer. Water with a higher temperature is extracted at deeper reservoirs [2]. The mass flow through the HEX is determined by the pump in the production well. An important part of the geothermal installation are the filters in the geothermal reservoirs. The filters remove solids out of the water in order to protect the heat exchanger and the wells of the geothermal plant. The well pump must run between a minimal flow and maximum flow. If the flow rate is too low, the reservoir becomes clogged. If the flow rate is too high, the filter installation will be damaged [13]. The heat production from geothermal sources is therefore poorly adjustable and cannot be adjusted to large fluctuations of the heat demand. For this reason, geothermal systems cover generally a base load and the peak demands need to be supplied by other sources [10].

District heating systems (DHS) are networks which collect heat from producers and provide heat for the collective heating demand of buildings and industry. DHS can be divided in High Temperature (HT), with supply temperature > 70 , Medium Temperature (MT, [45 - 70 ºC]) and Low Temperature (LT), with supply temperature below 45 ºC, networks [17, 21].

A distinction is made between space heating demand and domestic hot water heating (DHW) demand. Heat gains and losses inside a building depend on transmission, ventilation & infiltration, internal gains and solar gains [29]. DHW is needed for the bathroom and for cooking purposes. The sum of these two demands for the whole neighborhood is the heat demand of the district.

Lundström & Wallin [19] have shown that the peak heat demand of a district is mainly caused by the space heat demand in the winter, provided that a boiler is used for DHW storage and peak shaving. In the summer, the peak heat demand is caused by the DHW use. In 2016, the Biesdonk district of Breda (the Netherlands), with 1650 homes, consumed 14813 MWh for heating purposes and 3451 MWh for DHW [31]. When designing a DHS making use of data for a single dwelling, the heat demand of the DHS can be estimated by multiplying these data with the number of dwellings in a district making use of the corresponding simultaneity factor. The heat demand determines the type and size of the pipes [19]. Because LTDH use low supply temperature, the temperature difference between the supply and return pipe is small. To supply the same amount of heat through an LTDH instead of a HTDH, the diameters should be larger. If the peak heat requirement is supplied through the pipe network, the diameters of the pipes need to take the peak load conditions into account. If only the basis heating demand goes through the pipe network and the peak heat demand is produced near the dwellings, the diameters of the pipes can become smaller [19]. Another limitation is the supply of DHW. In the Netherlands DHW should be delivered at least at 60 °C, otherwise legionella can possibly develop in the water. For LTDH this is difficult to realize, so a need for post-heating is required. Post-heating can be done with a Booster Heat Pump (BHP) or an electric heating element. If the DHS water enters the house with 60 °C or higher, only a heat exchanger (HEX) is needed.

The heating needs differ on daily base and on seasonal base. Peak demands occur in the morning and evening on a daily base. Residents wake up in the morning and prepare to start their day. During the day, fewer people are present in a neighborhood, resulting in a lower heat demand. Most of the residents come back to their homes in the evening increasing the heat use. On a daily base, the peaks depend mainly on when the residents are at home. Occupancy level of people can be estimated using Ahmed et al. [3]. Seasonal peaks are different. These are based on the weather. In the winter, when the temperature is lower, heat demand is higher than in the summer.

According to Rezaie & Rosen [22], an DHS can be divided into three subsystems: heat production, heat transportation and heat consumption. The heating system for a neighborhood can be done collectively or decentralized [22]. The difference is the location of the heat source. In a collective heating system, the heat is produced far from the location of the end-users and it produces heat for the whole district and distributes the heat via a large distribution network. A decentral heating system produces heat close to the end-user and has a smaller or no distribution network. The same applies for storage methods. Collective storage is located far from the end-user and decentral storage is located close to the end-user. Collective storage depends on the seasonal heat demand and decentral storage depends on hourly demand [4]. In general, it can be said that decentral heating systems become more relevant for low density neighborhoods and collective heating is relevant for high density neighborhoods.

According to Alva et al. [4] and Lund et al. [18], the aquifer thermal energy storage (ATES) and hot water tank storage are currently the most suitable storage methods for an LTDH, because these systems have low installation costs and are more frequently applied than other technologies. ATES is a technology which is used for seasonal storage. Heat is extracted from the ATES during the winter and heat is injected during the summer. ATES works as follows. An ATES consists of two wells (a doublet) or multiple doublets. Groundwater from the cold well is injected at increased temperature in the warm well, when there is an excess heat production from the LTGH. In winter, when the warm well is charged, heat from the warm well is transferred to the grid and cooled groundwater is injected in the cold well. The recovery efficiency of an ATES is defined as the amount of injected thermal energy that is recovered after the injected volume has been extracted [5]. The recovery efficiency increases when the storage temperatures of the DHS decrease. The heat loss that occurs is due to displacement by groundwater flow and by dispersion and conduction.

To investigate which LTDH design can supply the peak demand most efficiently and sustainably, the following KPIs have been considered.

- CO_2 emission: the CO_2 emission of the system should be as low as possible.
- Levelized cost of energy (LCOE): the costs of produced kWh of heat should be as low as possible.
- Electricity use: Electricity use should be as low as possible to prevent overloading of the electricity net.
- Availability: the supply (including stored heat) should always meet the demand.

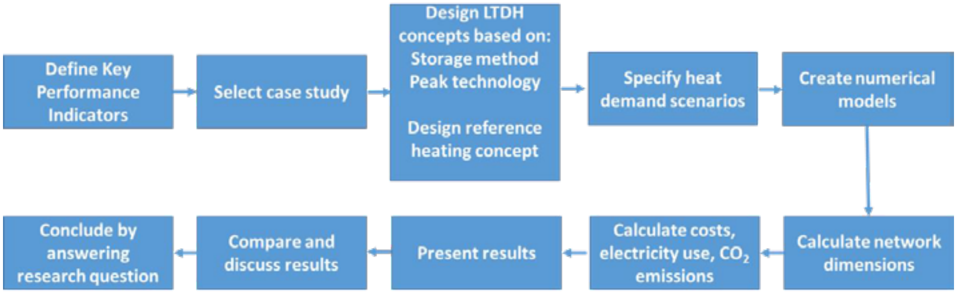

Fig. 1. Methodology used in the present study.

As illustrated in Fig. 1, this study starts with the definition of the key performance indicators (KPI) used for the evaluation of the different LTDH systems, the definition of the types of housing in the urban area considered and the quantification of the related heating requirements in these buildings. The alternative network designs considered for the LTDH network are created. The typology of the considered district allows for the determination of the required distribution line lengths and sizes. Numerical models are introduced to quantify the yearly energy requirements of the different options. Finally, the predicted electricity use, costs and CO_2 emission of the different network designs are compared to identify the most suitable solution.

2. Case study and LTDH designs

2.1. District heating location and heating requirement

Biesdonk, a district of Breda dating from the 1970's, has been selected for the present case study. In 2015, Biesdonk had 4995 residents and 2230 dwellings. The heat demands of 650 terraced houses and 1000 apartments are known. The terraced houses are low-rise buildings. Other buildings, such as shopping centers, schools, and churches are also present in the area. Heat demands for those buildings are not known and are outside the scope of this study. A map of Biesdonk and its heating demand are presented in Fig. 2. In the figure the space heating is given by the blue line and the water heating consumption by the red line.

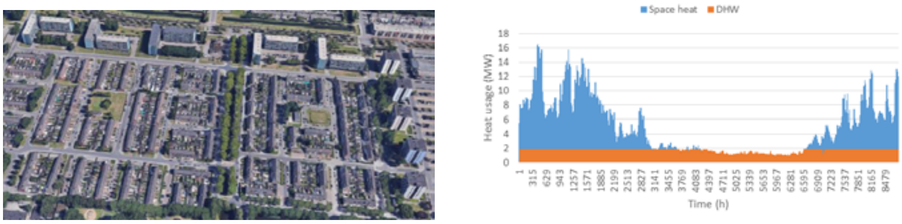

Fig. 2. District Biesdonk in Breda selected for implementation of the LTDH designs (left) and heating requirement for 650 terraced houses and 1000 apartments in 2016 (right).

2.2. Network designs

The LTGH source considered in this study is located in an aquifer 750 m below surface level and delivers 150 m^3/h (41.7 kg/s) in the heating season and 90 m^3/h in the summer of ground water with a constant temperature of 30 ºC. This flow can be directly delivered to the district network making use of a heat exchanger at the well head or can be directly upgraded with a heat pump at the well head and delivered to the network at higher temperature.

Since the flow delivered by the LTGH source is continuous throughout the year, a heat storage facility is required which could be an aquifer closer to the surface maintained at the temperature level of the distribution system. This aquifer serves then the whole district and can cover the season peak needs. Alternatively, a hot water tank can be used on a decentral level to cover the daily peak heating needs. Additionally, the network requires an auxiliary boiler to cover peak loads which cannot be covered by the storage facilities. This boiler can be installed at collective level or decentral at user level.

The return temperature for the designs which use central heat pumps is 32 ºC. Existing radiators can create a return temperature of 30 ºC, but the return water will be increased by 2 ºC due to losses in the supply set at home level [20]. If the ATES provides cold water to the return pipes, the temperature will increase as well. The return temperature for the designs without central heat pumps is 18 ºC. This can be achieved by the decentral heat pumps [30].

Table 1 gives an overview of the considered network designs.

Table 1. Evaluated designs of the network with individual air source heat pumps as alternative to the network (design 6).

Design	LTDH supply temperature	Collective storage	Decentral storage	Collective peak	Decentral Peak	DHW heating
1 – HT boiler	70 °C	ATES	none	boiler	None	HEX
2 – HT elect.	70 °C	ATES	water tank	none	electrical	HEX
3 – MT boiler	50 °C	ATES	none	boiler	None	booster HP
4 – MT elec.	50 °C	ATES	water tank	none	electrical	booster HP
5 – LT HP	30 °C	ATES	none	none	HP	HP
6 – air HP	none	none	none	none	HP	HP

Fig. 3 gives a schematic representation of design 1 which consists of a central heat pump that upgrades the heat from the geothermal source to 70 ºC, an aquifer that collects the excess heat available from the network to deliver it when needed, a (biomass) boiler to cover the collective peak requirement and a HEX to deliver the individual DHW needs.

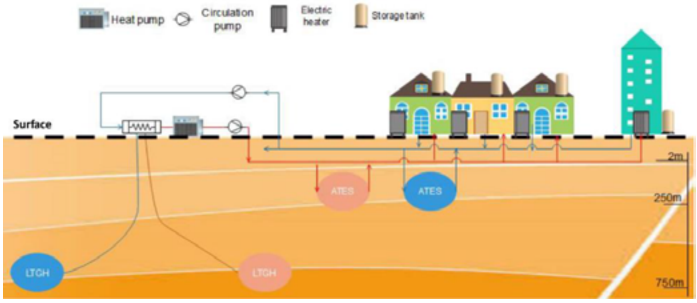

Fig. 3. Schematic of network design 1 showing how the different parts of the system are connected.

Fig. 4 is a simplified flow diagram of the network illustrating the log-mean temperature differences (LMTD) during heat exchange in the different parts of the system.

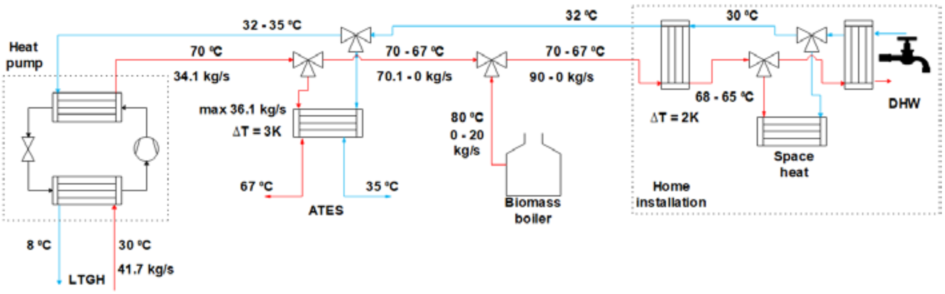

Fig. 4. Flow diagram of network design 1 showing flows and corresponding temperature levels. The supply line is given in red while the return line is printed in blue. The mass flow to / from the aquifer is limited to 130 m^3/h [9, 27].

3. Matching energy demands to energy availability

3.1. Network sizing

The heat supplied by the LTGH source can be obtained with eq. (1) where the temperature of the production well is constant at 30 °C and the injection temperature depends on the network design. The volume flow of the geothermal well is 150 m³/h (41.7 kg/s) in the heating season and 90 m³/h (25 kg/s) in the summer period.

$$\dot{Q}_{LTGH} = \dot{m}_{LTGH} \cdot c_{p\_LTGH} \cdot (T_{well} - T_{injection}) \quad (1)$$

When a heat pump is used, the heat supplied to the network is enlarged as given in eq. (2) with *COP* the performance of the heat pump.

$$\dot{Q}_{LTDH\_HP} = \frac{COP \cdot \dot{Q}_{LTGH}}{COP - 1} \quad (2)$$

The mass flow through the LTDH follows then from eq. (3).

$$\dot{m}_{LTDH} = \frac{\dot{Q}_{LTDH\_HP}}{c_{p\_LTDH} \cdot (T_{supply} - T_{return})} \quad (3)$$

The type of network material and size is determined by the heating demand per pipe line. First a network is created. The approach is based on Frederiksen & Werner [12]. The LTGH is located in the center of the district, since in this way the distances between the heat supply plant and each substation are as short as possible and therefore heat losses are smallest. For the district Biesdonk, the LTGH can be located in a small park. The network is divided into 4 sectors; A in north-west (with 360 apartments and 150 terraced houses), B in north-east (with 240 apartments and 200 terraced houses), C in south-west (with 300 terraced houses), and D in south-east (with 320 apartments and 100 terraced houses). According to Verhaegh [31], in 2016 sector A had a heating requirement of 5355 MWh, B of 6358 MWh, C of 3293 MWh and D of 4200 MWh. Pipes leaving the LTGH station are large and decrease step by step to small pipes as the network approaches the individual users. The heat transported through the pipes depends on the number of homes in a street. The heat demand is calculated for the worst case scenario. If the flow velocity exceeds 3 m/s or the pressure drop exceeds 400 Pa/m diameter adjustments need to be done. The Wanda software of Deltares [8] is then used to develop the physical infrastructure for the heat distribution network including pipe diameters and circulating pump selection. Fig. 5 illustrates the approach.

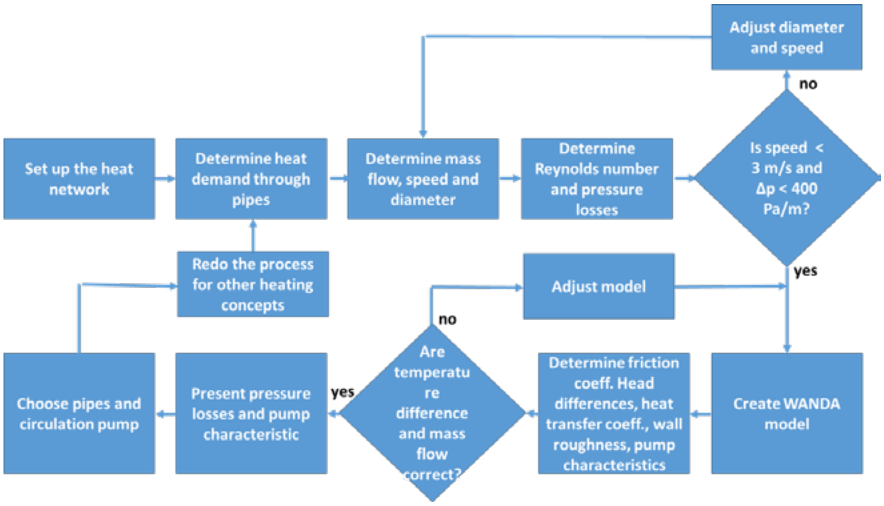

Fig. 5. Flow chart of the network sizing making use of the software Wanda of Deltares (2019).

3.2. Energy balance

Since the LTGH source delivers a fixed amount of energy, a yearly energy balance is obtained by varying the number of users connected to the network and so changing $\dot{Q}_{demand}$ in eq. (4).

$$\dot{Q}_{demand} + \dot{Q}_{loss} = \dot{Q}_{LTGH} + \dot{Q}_{peak\_supply} \tag{4}$$

where the losses result from losses in the aquifers, in the network pipe lines and in the heat exchangers. The heat losses from the aquifer have been considered by assuming storage temperature dependent recovery efficiencies as proposed by de Wit-Blok [7]. The ATES at HT (67 ºC, designs 1-2) is assumed to have a heat recovery of 65%, at MT (47 ºC, design 3-4) of 75% and at LT (27 ºC, design 5) of 85%. The pipe lines losses have been adapted from Thermaflex [28], a company specialized in the manufacturing of insulated tubes for LTDH networks. The losses depend mainly on tube size and temperature level of the network and vary from a factor larger than 3 for 70 ºC in comparison to 30 ºC for the smaller inner diameters (14.4 mm) to a factor 2 for the larger tubes (138 mm). The losses from heat exchangers are generally small and have been determined by estimating its *UA* values from external surface to environment and the temperature difference to the environment. The heat exchangers are assumed to be insulated so that the *U* value is around 1.5 $Wm^{-2}K^{-1}$ and its surface is around 12 m^2. Fig. 6 in combination with eq. (5) illustrates how the capacity of the ATES storage has been determined.

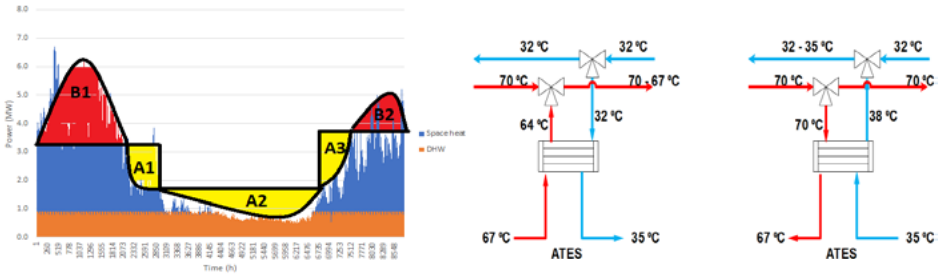

Fig. 6. Peak shaving with ATES. The extra heat delivered by the well given in yellow can be stored to be used to cover the peak loads marked in red (left). Temperatures differences in heat exchanger during discharging and charging of the ATES (right).

$$Q_{ATES} = \frac{(B_1 + B_2)}{\eta_{recovery}} = (A_1 + A_2 + A_3) \tag{5}$$

The sizing of the ATES is based on Drijver et al. [9] and Sommer [27]. The ATES is installed at 250 m depth and the maximum mass flow rate is 130 m^3/h, consistent with the geo-hydrological conditions in the Netherlands. The supplied power is calculated with eq. (6).

$$\dot{Q}_{ATES} = \dot{m}_{ATES} \cdot c_{p_{ATES}} \cdot (T_{ATES\_supply} - T_{ATES\_return}) \tag{6}$$

The COP of the collective heat pumps is obtained from eq. (7) with T_H the thermodynamic average temperature at the DH side and T_C the thermodynamic average temperature at the geothermal well side. The second law efficiency, η_{Carnot}, has been taken as 0.30, in agreement with de Vrieze [6]. The COP of the collective heat pumps (designs 1-4) is then 3.2 for the 70 ºC network and 3.9 for the 50 ºC network. The decentralized water-water heat pumps (network design 5) will have COPs of 4.2 and 3.6 respectively for space heating and DHW purposes.

$$COP = \eta_{Carnot} \cdot \frac{T_H}{T_H - T_C} \tag{7}$$

In network design 6, air to water heat pumps are used to deliver the heating requirement. These heat pumps extract heat from the environmental air and convert it into useful heat for a water circulation circuit. The *COP* therefore depends on the outside temperature. Table 2 presents experimental *COP* values of air – to – water heat pumps at different outside temperatures. The temperature at the inlet of the radiators is 55 ºC. At ambient temperatures below 5 ºC, frost develops on the surface of the evaporator which reduces the performance of the heat pump. The frost layer reduces the rate of heat transfer in the evaporator because it acts as a thermal insulation. Furthermore, the frost layer blocks part of the air flow passage through the evaporator which causes a further reduction of the performance. To prevent this phenomenon, an electrical resistance is installed in the heat pump which is activated when the ambient temperature is lower than 5 ºC. The power consumed by the resistance causes a decrease of about 10% in the COP [26].

Table 2. *COP* of an air-water heat pump delivering heat at 55 ºC, adapted from Ertesvåg [11].

Ambient temperature [ºC]	-9	-7	-5	-3	-1	1	3	5	7	9	11	13
COP_{HP}	1.9	2.1	2.2	2.4	2.5	2.6	2.7	2.8	3.2	3.3	3.5	3.8

If the network has a supply temperature below 60 ºC, a booster heat pump (BHP) is required to prepare the DHW. According to Kleefkens et al. [14], when the supply temperature to the BHP is 45 ºC, the COP is 4.2. The required electricity is calculated with eq. (8), where $\dot{Q}_{HP}$ is the power delivered by the heat pump.

$$\dot{W}_{elec} = \frac{\dot{Q}_{HP}}{COP_{HP}} \tag{8}$$

The CO_2 emission considered in this study is only caused by the use of electricity and biomass. Regular geothermal sources produce extra CO_2, because natural gas is released. However, the considered LTGH source is drilled only at 750 m depth and in aquifers where no natural gas is available [25]. The emission factor of electricity and biomass in the Netherlands are currently 0.649 kg/kWh and 0.093 kg/kWh [24].

The price of electricity has been taken as 0.18 €/kWh and of biomass fuel as 0.04 €/kWh [1].

3.3. Levelized cost of energy (LCOE)

The *LCOE* calculates the costs per amount of energy delivered over a certain time. This is summarized in eq. (9).

$$LCOE = \frac{\sum_{t=0}^{t=n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=0}^{t=n} \frac{Q_t}{(1+r)^t}} \tag{9}$$

Where *LCOE* is expressed in €/kWh, the delivered energy (*Q*) is the heat delivered to the users of the LTDH network. The life time (*n*) is the number of years the systems runs (here assumed to be 30 years). The years are expressed in (*t*) and run from year 0 to year 30. The interest rate (*r*) is assumed to be 6%, because a transformation in energy supply is a risk-full project [16]. The investment costs (*I*), maintenance costs (*M*), and fuel costs (*F*) are the total costs in a certain year. The costs in year 0 are the investment costs (CAPEX). During all the other years the costs consist of operational and maintenance costs (OPEX).

4. Results and discussion

4.1. Amount of auxiliary heat required

The values of all relevant variables have been calculated on an hourly basis for the whole year. As an example of the results, the difference between the power delivered by the LTGH in the two coldest weeks of the year and required by the users of the network is shown in Fig. 7 (a) for network design 1 (70 ºC). The figure makes clear that in these two weeks most of the time the power delivered by the geothermal source is not sufficient to cover the heating requirement. Some of this extra power can be delivered from the ATES as shown in Fig. 7 (b). The remaining power needs to be delivered by the auxiliary boiler. This contribution is shown in Fig. 7 (c).

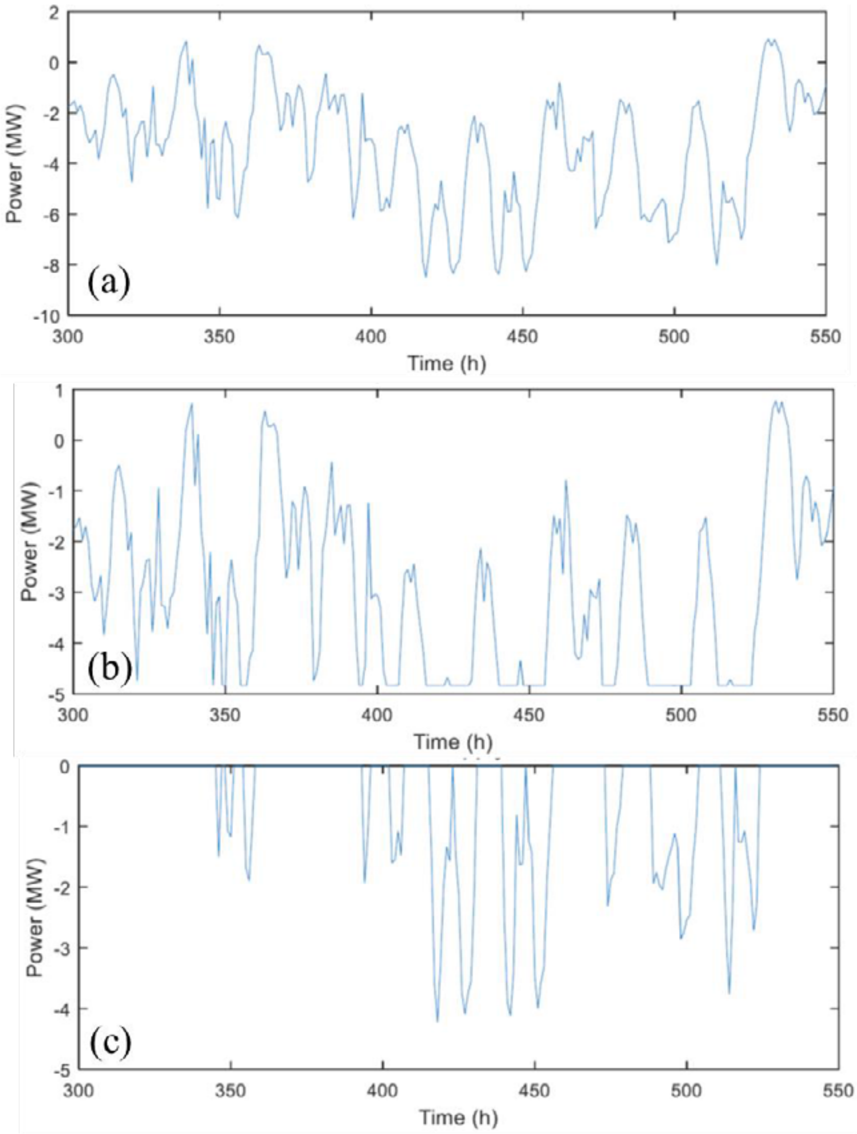

Fig. 7. Difference between available LTGH power and required thermal power by the network users during the two coldest weeks (a) for network design 1 (70 ºC). Power delivered by the ATES in these two weeks (b) and power provided by the auxiliary boiler to compensate for the shortage of power (c).

In a similar way the amount of power delivered by the auxiliary boiler has been determined for the whole year and for the different network designs.

4.2. Impact of temperature level of the network

Operating the network at a lower temperature imposes the use of larger flows and so larger tube sizes and pumps. Table 3 illustrates the impact of network design (and so its temperature level) on flows, pressure drop and tube sizes.

Table 3. Impact of network design in relevant parameters of the network. The details of the designs are listed in Table 1.

	Design 1	Design 2	Design 3	Design 4	Design 5
Flow rate [m^3/h]	6 x 55.0	6 x 30.7	6 x 108.5	6 x 56.0	6 x 110.4
Largest internal tube size [mm]	102	90	138	102	138
Pressure drop [bar]	5.4	4.8	6.5	5.7	7.0
Yearly heat losses network [MWh]	3741	3346	2724	2637	1682
Peak power of LTDH [MW]	13.47	10.25	13.47	8.76	10.21

4.3. Results for KPIs

Table 4 shows the values obtained for the KPIs defined in section 1 applied for the different designs. In bold the best performing designs.

Table 4. KPIs for the different network designs. The details of the designs are listed in Table 1.

	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
CO_2 emission in 30 years [ton CO_2]	52.5	52.2	48.5	48.8	**31.8**	39.5
LCOE [€/kWh]	0.198	0.186	0.222	0.201	**0.168***	0.202*
Yearly electricity in peak [MWh]	**509**	613	528	785	527	823
Yearly heat peak source [MWh]	233	**29**	741	392		
Yearly operation peak source [h]	135	**18**	259	151		

*This assumes that the heat pump [€ 2500. (design 5) and € 7800. (design 6)] is invested twice (once in the 15 years).

Fig. 8 summarizes the performance of the different designs in comparison with the use of individual air-water heat pumps per user (design 6). The figure only considers the most relevant KPIs: CO_2 emissions and *LCOE*.

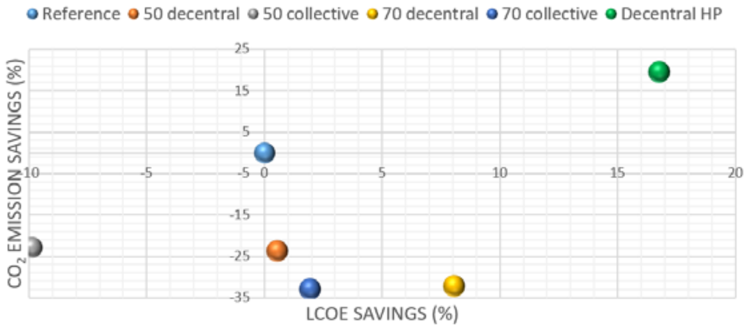

Fig. 8. Visualization of the performance of the different network designs in comparison to design 6 (no network). See Table 1 for network design details. Design 1 is indicated as 70 collective, 2 as 70 decentral, 3 as 50 collective, 4 as 50 decentral and 5 as decentral HP.

Fig. 8 shows that only design 5 (network at 30 ºC) performs better on both CO_2 emissions (19.5% less emissions then reference design) and *LCOE* (16.8% lower *LCOE* then reference design). Design 2 also leads to a significant but lower *LCOE* reduction (7.9%) but at the same time leads to a significant increase of the CO_2 emissions: +32.5%.

5. Conclusions

The supply temperature of the LTGH source has an influence on the *COP* of the heat pumps. Since the heat pumps of the LTGH use most of the total electricity, the electricity use depends a lot on the supply temperature of the LTGH source. This can be seen in the *LCOE* and CO_2 emissions as well. If the supply temperature of the LTGH source can be increased, the heat pumps require less electricity what reduces the CO_2 emission and costs for the complete system.

The best way to meet the heat demand in existing Dutch dwellings, with LTDH and an LTGH as main source is an LTGH with decentral heat pump for every single home. This LTDH concept saves 19.5 %, 16.8 %, and 36.0 % on the CO_2 emission, *LCOE*, and electricity use in peak load hours compared to an all-electric scenario.

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