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# The temperature distribution in the ground on the two types of pipes of underground heating network

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## Abstract

District heating systems commonly utilize pre-insulated pipes arranged in either a parallel or TwinPipe configuration. This study compares the temperature distribution in the ground, as determined by a numerical 3D model, with experimental measurements conducted on a dedicated test setup. The analysis includes several district heating pipe variants (DN40, DN50 and DN65), and their counterparts in a single parallel pre-insulated system. The results obtained from laboratory experiments and numerical simulations show strong agreement, confirming the reliability of the proposed approach. The novelty of this work lies in the integration of experimental data and numerical simulations to improve the accuracy of heat loss estimations. The relative error between the computational and experimental models remains below 10%, ensuring high precision in the findings. The presented results provide valuable design insights for optimizing insulation thickness and pipe layout configurations in district heating networks. These findings contribute to the development of more efficient and sustainable thermal energy distribution systems.

**Keywords:** District Heating Network; Heat loss; Heat transfer; Temperature distribution

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## 1. Introduction

In Europe, more than 40% of final energy is used to heat buildings [1]. One way to provide heat is through district heating networks. It works especially well in large cities where these networks are very extensive and access to them is more easily available. In order to achieve the most energy-efficient district heating network (DHN), it is necessary to choose the appropriate source of heat for its supply and its distribution method. The use of heat pumps and other renewable energy sources is considered to reduce the amount of fossil fuel use and greenhouse gas (GHG) emissions, as discussed by Lund et al. [2].

For transporting the energy carrier within the DHN, pre-insulated pipes are currently used in single and TwinPipe arrangements. Both types of pipes can be used in underground and aboveground networks. When delivering the medium to the building at the required temperature to compensate for heat losses, it is necessary to use the required materials and pipes that will ensure it. Maximizing energy efficiency requires minimizing heat losses in the pipes. The analysis of energy efficiency of

## Nomenclature

$D$ – diameter, m
$h$ – heat transfer coefficient, W/(m$^2$ K)
$H$ – depth of foundation, m
$k$ – thermal conductivity, W/(m K)
$q$ – heat losses, W/m
$R$ – thermal resistance, (m K)/W
$t$ – fluid temperature, °C

### Greek symbols

$\rho$ – density, kg/m$^3$
$\sigma$ – relative error, %

### Subscripts and Superscripts

$gr$ – ground
$ins$ – insulation
$r$ – return
$s$ – supply
$w$ – wall

### Abbreviations and Acronyms

BEM – boundary element method
CIPP – cured-in-place pipe
DHN – district heating network
FEM – finite element method
FVM – finite volume method
GA – genetic algorithm
GHG – greenhouse gas
TOTS – two supply/one return, triple pipe structure
5GDHC– 5th generation district heating and cooling (network)

such district heating networks is investigated in many works, including pipes located in the ground.

The approach to thermal-ecological analysis was presented in the paper of Ziębik and Stanek [3]. The method uses cumulative exergy consumption and thermo-ecological costs as criteria in the analysis. The authors advocate the application of these criteria to overall processes instead of local exergy efficiency studies. However, the illustration of the concept is not well developed leaving the need for a more systematic presentation of the approach.

One possible measure for reducing heat losses is to lower the operating temperature levels of the fluid circulating inside the DHN. In 3$^{rd}$ generation DHN, the supply operating temperature is $t_s < 100$°C and return $t_r < 45$°C; in 4$^{th}$ generation DHN, these parameters take values for the supply temperature $t_s \sim 70$°C and return $t_r \sim 25$°C [4]. Fourth-generation systems should involve integration of renewables into the network [5]. If, in addition to heating, the district heating network also provides cooling, this is referred to as 5$^{th}$ Generation District Heating and Cooling Network (5GDHC) [6].

Merlet et al. [7] proposed a methodology to optimize the multi-stakeholder temperature reduction in the design of district heating distribution networks. The authors applied identification of the system bottlenecks and focused the retrofit measures on them, formulating dynamic optimisation problems.

The energy and economic benefits of reducing grid temperatures using different heat sources have been analysed by Geyer et al. [8]. The authors discussed that in the case of alternative heat technologies, such as heat pumps and solar panels, higher monetary sensitivity is observed compared to traditional heat technologies. Thus, future heat networks are expected to have higher economic benefits and monetary savings.

The economic optimisation of the insulation thickness of buried double pipes was analysed by Li et al. [9] aiming to minimise energy losses. The developed a model to optimise insulation and minimum total annual cost, and demonstrated the different effects of sensitivity factors on the parameters. The focus was on only one type of pipe found in the district heating network studied.

The thermal and economic analysis was made by Nowak-Ocłoń and Ocłoń [10]. It shows, by means of an analytical heat loss model, the cost effectiveness of TwinPipe in comparison with various types of single pre-insulated pipe. However, the heat loss here was determined in a simplified one-dimensional approach.

Ocłoń et al. [11] in another paper made a comparison between a numerical method and an analytical method for determining heat loss in underground heating network pipes. The calculations were performed for different diameters of two types of pipe systems: single pipes and TwinPipe arrangement. Differences between the results of calculations using the analytical model (1D) and the numerical model (2D) did not exceed 10%. The three dimensional space was neglected there.

Wang et al. [12] in their work proposed a method for estimating the heat loss of a ground heat network based on hourly measurements in each section of the network, which a genetic algorithm (GA) was used to solve. This method of optimization makes it possible to detect a more precise location of insulation or conductor defects in the network. The calculation results showed good agreement with the measured results. This model may not be suitable for real-time applications where computer resources or high-speed data processing capabilities may be limited.

Chicherin [13] in his work proposed another way to determine heat loss. He created a model that took into account the correlation between the amount of heat produced and outdoor temperatures by considering a linear regression function. The difference between the results from this method and the results from the actual heat losses in the existing analysed network ranges from 0.4% to 1.2%. Sartor et al. [14] proposed a dynamic model that determines the temperature of the medium taking into account ambient losses and the thermal inertia of the pipe. The finite volume method (FVM) was used. The results from the 1D model were compared with the results from the 2D model. The calculations were made using ANSYS software. The method may have been validated on specific case studies in certain regions, which may limit its generalizability to other areas with different geographical, economic or infrastructural characteristics. Wider validation in different contexts would be required to ensure its wider applicability.

Danielewicz et al. [15] compared the results of numerical calculations of heat loss in pre-insulated pipes with the results of in-situ measurements. The validation process confirmed the high quality of the model, as the differences between the ground temperatures were about 0.1°C. The calculations were carried out for a single type of pre-insulated pipe laid in parallel. The three-dimensional numerical model is computationally demanding, which may limit its practical application in large-scale or real-time scenarios. A simplified model was presented in the work of Jakubek et al. [16]. They compared the results of heat losses in the ground calculated by analytical solution (1D model) with the measurements on the dedicated experimental setup. Calculations were performed for different diameters (DN40, DN50, DN65) and pipe types: TwinPipe system and a single pre-insulated system. The difference between them was less than 10% based on the type of system.

Chen et al. [17] proposed a mathematical model for calculating the economic efficiency of a pipeline network by optimising the structural parameters involved in laying these pipes, based on the TOTS (two supply/one return, triple pipe structure) heat loss theory of a fourth generation district heating system. Suitable parameters were identified for which the total loss cost would be the lowest. Thermal analysis of the same fourth generation TOTS pipe system was analysed in the article by Xu et al. [18]. The heat losses for this type of network system have been calculated using an analytical model, and the numerical simulations have a high accuracy, with a deviation of 2%. The proposed heat loss model provides an innovative solution for low temperature district heating systems. It introduces additional complexity in terms of design, installation and maintenance compared to traditional two-pipe systems. It can lead to higher initial costs and requires specialist knowledge. Further research and validation is needed to assess its practicality, economic viability and long-term performance under different real-world conditions.

An analysis of the energy efficiency of another type of district heating network: flexible pre-insulated double pipes with symmetrical or asymmetrical insulation, double pipes and triple pipes was carried out by Dalla Rosa et al. [19]. Using a 2D model based on the Finite Element Method (FEM), the heat loss was determined and the results were verified with good agreement with experimental measurements and analytical formulae. The energy saving potential of asymmetric double pipe insulation, double pipe insulation and triple pipe insulation is about 10%, depending on the type of system. The method is based on simplifications: homogeneous soil conditions, constant flows or thermal steady states, which may not reflect all the complexities of real district heating systems. In order to apply it more widely, further validation would be required, taking into account the specific context, economic factors and potential technological advances.

Krawczyk and Teleszewski [20], in their work, proposed changing the cross-sectional geometry of the thermal insulation in double heating from round to ovoid in order to reduce heat losses in networks. Heat loss was determined using a boundary element method (BEM) plotting program, and the results showed that the larger insulation area in the supply pipe contributed to a reduced heat flux density around the supply pipe, resulting in a significant reduction in heat loss. Due to geographical limitations, the specificity of the solutions used, and the need for further long-term analyses, a cautious approach is necessary when attempting to generalize the results to other heating systems.

Teleszewski et al. [21] proposed the use of a quadruple-heated pre-insulated network and utilized a 2D numerical model to compare the heat loss results of single and double pipes. The results contributed to a significant reduction in heat losses compared to the existing single pre-insulated network (up to 57.1%). To apply the results on a larger scale or in other regions, further research should be conducted, including an economic assessment of this solution and its impact on the operational flexibility of the heating system.

Jing et al. [22] proposed the use of cured-in-place pipe (CIPP) liners with improved insulation function to reduce heat loss, which reduced the heat loss of the ageing pipe by 55.4% in numerical calculations. To better assess the potential of the proposed method, further research and validation in various contexts are necessary.

The presented studies have demonstrated methods for determining heat losses and their reduction in district heating networks. To gain a better understanding of the problem in these networks, it is also necessary to consider its impact on the ground during operation. In this article, the temperature distribution in the ground during the operation of district heating networks was analysed for two of the most popular types of pipes: single parallel pre-insulated pipes system and TwinPipe system (two pipes in one insulation). The calculations were carried out on a 3D model using CFD analysis in Ansys software [23] for three different diameters: DN40, DN50 and DN65. The results were compared with test bench measurements.

## 2. Experimental setup

In this chapter, the experimental setup will be presented, where the operation of the heating network system was simulated. Temperature measurements were conducted on two representative types of pipes.

The experimental laboratory stand (Fig. 1) is used to determine the heat losses and temperature distribution in the underground district heating network. The analysis concerns two types of pipes – two separate preinsulated pipes (parallel layout) and two pipes in one preinsulated system (TwinPipe).

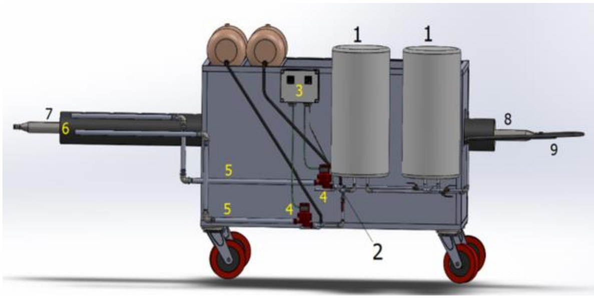

Fig. 1. The 3D model of the experimental laboratory setup.

The schematic diagram of the working medium is shown in Fig. 2. The demineralized water is heated to the desired temperature in two independent open systems (electric storage heater). The main function was the initialisation of the hydrostatic pressure for centrifugal pumps and removing the air bubbles from the system by using a non-pressure tank.

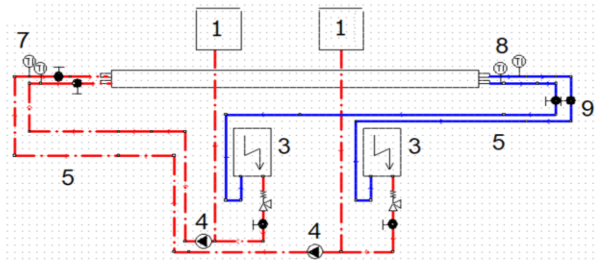


Fig. 2. The circulation flow diagram of the experimental-stand device.

The markings shown in Fig. 1 and Fig. 2 are described as follows:

- no 1 – the electric water heater tank for supply and return pipe,
- no 2 – temperature measurement sensors (two separate),
- no 3 – temperature regulators,
- no 4 – centrifugal pumps,
- no 5 – pipeline,
- no 6 – preinsulated pipe,
- no 7, 8 – temperature measurement points – inlet and outlet,
- no 9 – flow measurements point.

Each of the circuits has two separate temperature measurement sensors. Information about the liquid temperature goes to the temperature regulators which turn on or off the heater system. The refrigerant goes to the pumps forcing the liquid circulation. Then, through an insulated pipeline, it goes to one of the examined types of preinsulated pipes. The temperature is measured at the inlet and at the outlet of preinsulated pipes. Measurement of the flow with a turbine sensor is located at the outlet of the pipeline.

The temperature was measured with a digital thermometer, which measures temperatures from –55°C to +125°C (–67°F to +257°F). The accuracy from –10°C to +85°C is ± 0.5°C. The frequency of the measurements was 1 Hz at the same time in all measurement points. The location of the temperature sensors depends on the system used. The temperature is measured at the inlet and outlet of the pre-insulated pipes and on the outer surface of the casing. For the variant with single pipes, two sections of pre-insulated pipes with a length of 3.0 m (length of the insulated surface) were mounted to the device. The diagram of the location of the temperature sensors is presented in Fig. 3.

Sensors No. 3 – No. 6, No. 13 – No. 16 are sensors recording the temperature on the outer surface of the pipes. Sensors No. 9 – No. 12 are sensors recording the temperature of the soil between the supply and return pipes (Fig. 3).

The arrangement of the temperature sensors for TwinPipe configuration is shown in Fig. 4. The sensors were recording the temperature of the outer surface of the pipe in the soil. The parameters were checked before heating up activity. The estimated proportion of the clay and sandy soil in the compound is 50/50.

Sensors No. 3 – No. 6, are sensors recording the temperature on the outer surface of the pipe.

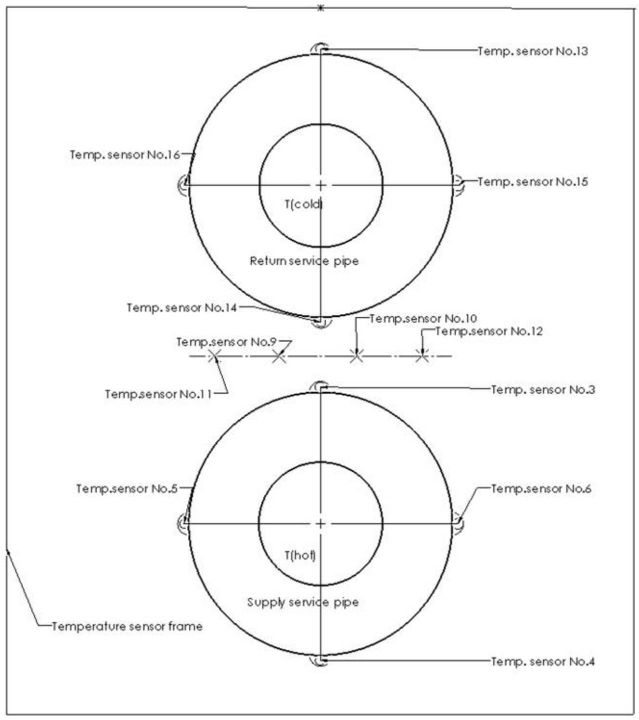


Fig. 3. Arrangement of temperature sensors.

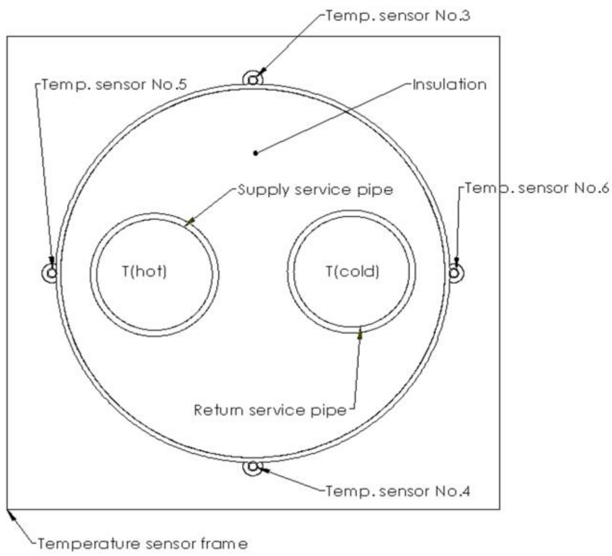


Fig. 4. Arrangement of temperature sensors for TwinPipe configuration.

## 2.1. Parameters of the soil, linear dimensions of single parallel pre-insulated system and TwinPipe system

The parameters of the soil used at the experimental laboratory setup are presented in the following:

- thermal conductivity coefficient: $k_{gr}$ = 2.2 W/(m K),
- degree of moisture: 24%,
- density: $\rho$ = 1800 kg/m$^3$.

The presented results refer to average parameters of the soil used in trials. The parameters were checked before heating up activity. Pure sandy soil is characterized by high proportion of the sand and little clay. They are quicker to warm up in comparison to clay soil but tend to dry in summer. The pure clay soil remains wet and coils in winter, clay soil has an ability to hold high amounts of water. In order to that warming up takes longer. The estimated proportion of the clay and sandy soil in the compound is 50/50.

Based on the research [23], the soil with 5% of humidity compared to the soil with 15% of humidity gives a 50% higher heat transfer coefficient, 0.62 W/(m K) and 1.20 W/(m K), respectively. The heat conductivity coefficient depends on the density of soil. For the humidity of 20%, and the densities of 1000 kg/m$^3$ and 2000 kg/m$^3$, it is 0.5 W/(m K) and 1.4 W/(m K), respectively.

The experimental laboratory stand was designed based on information included in standards for TwinPipes [24] and for single pre-insulated pipes in a parallel configuration [25]. Parameters of the pre-insulated pipes system and linear dimensions are shown as follows (Fig. 5).

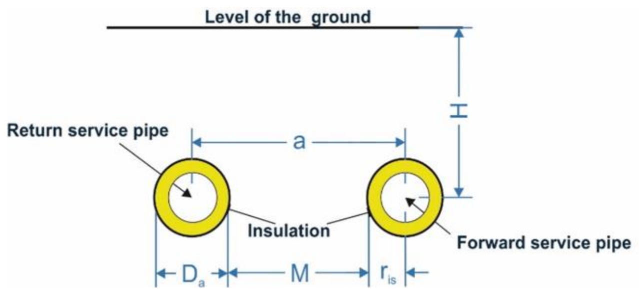


Fig. 5. Scheme of the underground preinsulated single pipe system.

Linear dimensions are included in Table 1.

Table 1. The parameters of the underground preinsulated parallel pipe system for DN40, DN50 and DN65.

| | DN40 | DN50 | DN65 |
|---|---|---|---|
| a [mm] | 170 | 170 | 170 |
| M [mm] | 30 | 45 | 60 |
| $D_a$ [mm] | 140 | 125 | 110 |
| H [mm] | 455 | 455 | 455 |
| $r_{is}$ [mm] | 70.0 | 62.5 | 55.0 |
| $h_m$ [mm] | 385.0 | 392.5 | 400.0 |

Material and insulation (polyurethane rigid foam insulation – PUR) properties meet the requirements included in the norm EN 253:2019+A1:2023 [26].

Parameters of the TwinPipe system and its linear dimensions are shown in Fig. 6 and in Table 2.

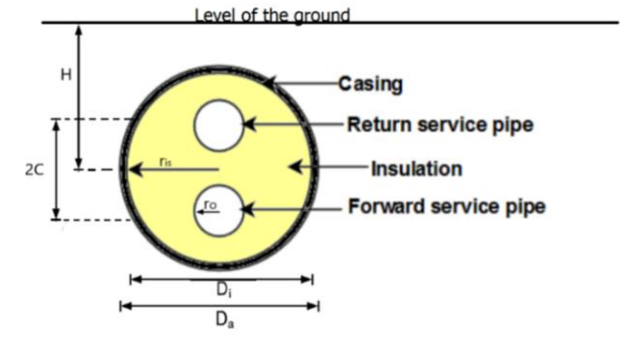


Fig. 6. Scheme of the underground TwinPipe system.

Table 2. The parameters of the underground TwinPipe system for DN40, DN50 and DN65.

| | DN65 | DN50 | DN40 |
|---|---|---|---|
| a [mm] | 48.05 | 40.15 | 34.15 |
| $D_a$ [mm] | 225.0 | 200.0 | 160.0 |
| H [mm] | 385.0 | 392.5 | 400.0 |
| $r_{is}$ [mm] | 108.3 | 95.8 | 75.8 |
| $r_o$ [mm] | 38.05 | 30.15 | 24.15 |

## 3. The numerical model

The temperature distribution analysis was conducted using Ansys software. DesignModeler was utilized for geometric modelling, while the Fluent module was employed for simulating temperature distribution in the ground near the district heating network [27]. The results were also compared with experimental data. A three-dimensional heat conduction equation is solved to determine the maximum temperature within the heating network $T = T(x, y, z)$. The heating network is composed of layers tube ($t$), insulation ($ins$) and ground ($gr$). The convective heat transfer occurs between the fluid flowing inside the supply ($s$) and return ($r$) tubes.

- For the tube domain:

$$k_t \frac{\partial^2 T}{\partial x^2} + k_t \frac{\partial^2 T}{\partial y^2} + k_t \frac{\partial^2 T}{\partial z^2} = 0; \qquad (1)$$

- For the insulation domain:

$$k_{ins} \frac{\partial^2 T}{\partial x^2} + k_{ins} \frac{\partial^2 T}{\partial y^2} + k_{ins} \frac{\partial^2 T}{\partial z^2} = 0\,; \qquad (2)$$

- For the ground domain

$$k_{gr} \frac{\partial^2 T}{\partial x^2} + k_{gr} \frac{\partial^2 T}{\partial y^2} + k_{gr} \frac{\partial^2 T}{\partial z^2} = 0, \qquad (3)$$

where: $x$, $y$ – are Cartesian coordinates of a specified point that belongs to the heat transfer domain, $k$ – is the thermal conductivity specified for the different computational domains, i.e. for the tube wall material $k_t$ = 30 W/(m K), for the insulation material $k_{ins}$ = 0.042 W/(m K), for the soil layer $k_{gr}$ = 2.2 W/(m K).

The boundary conditions are:

- For the supply pipe:

$$k_t \frac{\partial T}{\partial r}\bigg|_{r=r_{in}} = h_s(T - T_s); \tag{4}$$

- For the return pipe:

$$k_t \frac{\partial T}{\partial r}\bigg|_{r=r_{in}} = h_r(T - T_s), \tag{5}$$

where $r_{in}$ is an inner radius of the supply/return pipe; $h_s$ and $h_r$ are the water side heat transfer coefficients from the supply ($s$) and return ($r$) side.

The mesh boundary conditions are prepared in the Design Modeler module. The geometry and mesh discretization is shown in Fig. 7. The multizone method with prism mapping was applied. The minimum edge length is 0.13163 m. The number of nodes and elements are 68488 and 58265, respectively. The element size is defined as 0.008 m. Five layers of inflation with a 1.2 rate of growth are used on "hot" and "cold" areas.

Fig. 7. The geometry model after discretization process (mapped mesh type applied: prism).

The applied boundary conditions according to the temperature, thermal conductivity and fluid flow are as follows:

- Inlet_1:
  - Velocity magnitude: 1 m/s,
  - Fluid temperature: 85°C,
- Inlet_2:
  - Velocity magnitude: 1 m/s,
  - Fluid temperature: 45°C,
- Soil_clay:
  - Temperature: 19°C.

The number of iterations is 500. The parameters of the layers of each geometry correspond to the values obtained during laboratory investigations.

The temperature of the fluid inside the pipes was imposed as a boundary condition, with values based on the results obtained from laboratory experiments. The heat transfer coefficients on the fluid side ($h_s$, $h_r$) were assumed as constant values, in accordance with the model assumptions and based on the measurement data.

## 4. Results and discussion

The selected results of measurements, computations, and comparisons, covering three measurement series for different sizes of pre-insulated pipes in single parallel and TwinPipe configurations. The thermal conductivity of the insulation had been verified separately for each case. Temperature results are from the steady state thermal condition (approx. after 3.5 h of heating up). The initial temperature of the soil was used in the numerical simulation as input data.

The experimental data, computations, and comparison of results for the single parallel configuration pipes for different diameters are shown in Figs. 8–10. In these figures, (a) are the results from an experimental stand, and (b) are the results from temperature distribution simulations. The temperature values in the ground (nodes 9–12 in Fig. 3) are presented in Tables 3–5.

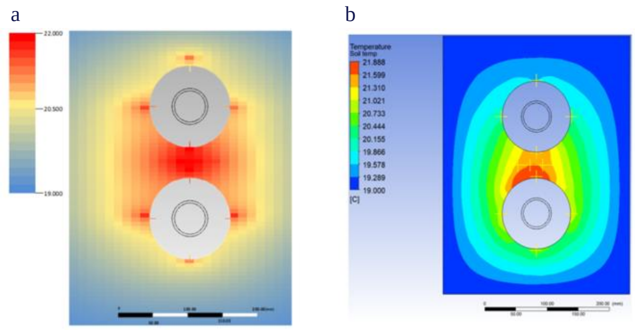


Fig. 8. Temperature distribution on the single parallel configuration DN40 – experimental stand (a), numerical simulation (b).

Table 3. The average temperature from an experimental stand and numerical analysis for single parallel configuration (DN40).

| | | Numerical simulation | Experimental stand | Relative error σ [%] |
|---|---|---|---|---|
| **Temp. of the soil between pipes [°C]** | No. 9 | 21.55 | 20.80 | 3.61 |
| | No. 10 | 21.55 | 20.55 | 4.87 |
| | No. 11 | 21.05 | 19.55 | 7.67 |
| | No. 12 | 21.25 | 19.90 | 6.78 |
| **Ave. temp. of soil [°C]** | | 21.35 | 20.75 | 2.89 |

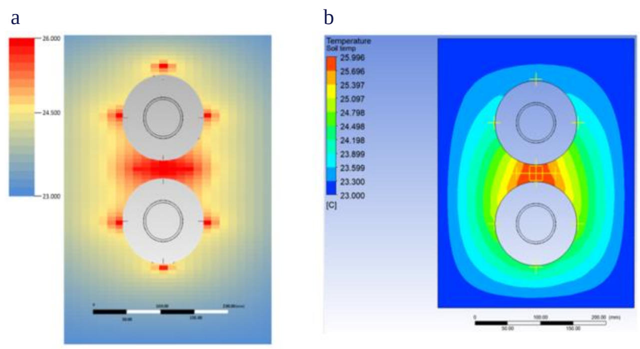


Fig. 9. Temperature distribution on single parallel configuration DN50 – experimental stand (a), numerical simulation (b).

Table 4. The temperature from an experimental stand and numerical analysis for single parallel configuration (DN50).

| | | Numerical simulation | Experimental stand | Relative error σ [%] |
|---|---|---|---|---|
| **Temp. of the soil between pipes [°C]** | No. 9 | 25.85 | 25.30 | 2.17 |
| | No. 10 | 25.85 | 25.75 | 0.39 |
| | No. 11 | 25.55 | 25.60 | 0.20 |
| | No. 12 | 25.55 | 24.60 | 3.86 |
| **Ave. temp. of soil [°C]** | | 25.70 | 25.30 | 1.58 |

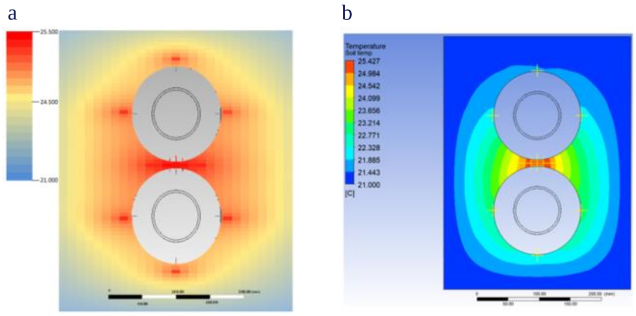


Fig. 10. Temperature distribution on single parallel configuration DN65 – experimental stand (a), numerical simulation (b).

Table 5. The temperature from an experimental stand and numerical analysis for single parallel configuration (DN65).

| | | Numerical simulation | Experimental stand | Relative error σ [%] |
|---|---|---|---|---|
| **Temp. of the soil between pipes [°C]** | No. 9 | 25.25 | 24.50 | 3.06 |
| | No. 10 | 25.35 | 24.25 | 4.54 |
| | No. 11 | 24.55 | 23.30 | 5.36 |
| | No. 12 | 24.65 | 23.20 | 6.25 |
| **Ave. temp. of soil [°C]** | | 24.95 | 23.80 | 4.83 |

The results of calculations for the second type of pipes configuration – TwinPipe system are presented below in Figs. 11–13. The temperature values in the ground (nodes 3–6 in Fig. 4) are presented in Tables 6–8.

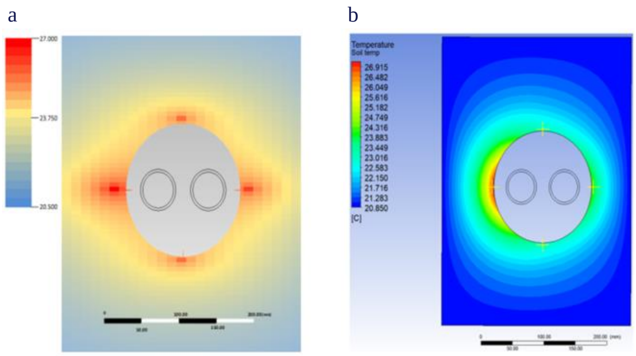


Fig. 11. Temperature distribution on TwinPipe configuration DN40 – experimental stand (a), numerical simulation (b).

Table 6. The temperature from an experimental stand and numerical analysis for TwinPipe configuration (DN40).

| | | Numerical simulation | Experimental stand | Relative error σ [%] |
|---|---|---|---|---|
| **Temp. of the soil between pipes [°C]** | No. 3 | 21.35 | 20.30 | 5.17 |
| | No. 4 | 21.45 | 20.40 | 5.15 |
| | No. 5 | 26.75 | 25.30 | 5.73 |
| | No. 6 | 22.85 | 22.40 | 2.01 |
| **Ave. temp. of soil [°C]** | | 23.10 | 22.70 | 1.76 |

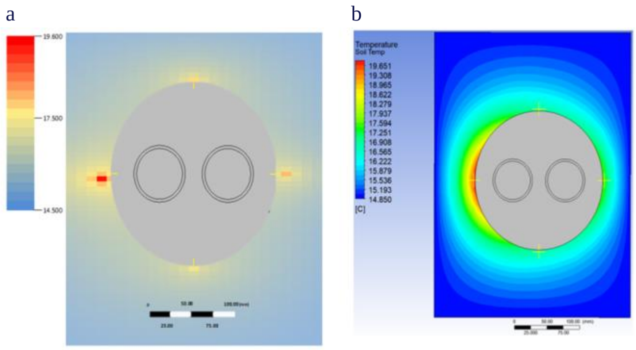


Fig. 12. Temperature distribution on TwinPipe configuration DN50 – experimental stand (a), numerical simulation (b).

Table 7. The temperature from an experimental stand and numerical analysis for TwinPipe configuration (DN50).

| | | Numerical simulation | Experimental stand | Relative error σ [%] |
|---|---|---|---|---|
| **Temp. of the soil between pipes [°C]** | No. 3 | 16.85 | 15.20 | 10.86 |
| | No. 4 | 16.75 | 15.30 | 9.48 |
| | No. 5 | 19.55 | 17.80 | 9.83 |
| | No. 6 | 17.45 | 15.60 | 11.86 |
| **Ave. temp. of soil [°C]** | | 17.65 | 16.00 | 10.31 |

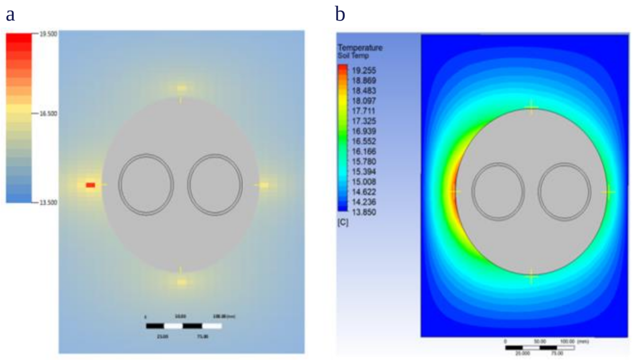


Fig. 13. Temperature distribution on TwinPipe configuration DN65 – experimental stand (a), numerical simulation (b).

Table 8. The temperature from an experimental stand and numerical analysis for TwinPipe configuration (DN65).

| | | Numerical simulation | Experimental stand | Relative error $\sigma$ [%] |
|---|---|---|---|---|
| Temp. of the soil between pipes [°C] | No. 3 | 15.75 | 14.00 | 12.50 |
| | No. 4 | 15.75 | 14.50 | 8.62 |
| | No. 5 | 19.05 | 17.30 | 10.12 |
| | No. 6 | 16.45 | 14.90 | 10.40 |
| Ave. temp. of soil [°C] | | 16.75 | 15.20 | 10.20 |

The difference between the numerical calculation and the measured results for the ground temperature distribution around the district heating network pipe varies between 0.2% and 12% (approximately 5% for single parallel pipes and 10% for TwinPipe).

Figures 8–13 show how to interpret the temperature distribution in the ground, where the greatest losses occur. Knowing these values gives you the opportunity to propose design solutions that will reduce heat loss in the areas concerned.

## 5. Conclusions

This paper presents an analysis of the temperature distribution in the surrounding soil, determined through numerical heat transfer simulations. The computed temperature values were compared with experimental measurements obtained from a dedicated test setup. The agreement between the experimental results and numerical modelling of the heating network's temperature distribution is satisfactory, with a relative error of less than 10%. Specifically, the difference between the computational approach and experimental data is approximately 5% for the single pre-insulated pipe system and 10% for the TwinPipe system. Additionally, the temperature drop between the heating medium and the surrounding ground is lower for the TwinPipe configuration.

The proposed model can serve as a practical tool for the design, optimization and retrofitting of district heating networks. Additionally, it can be extended to analyse the interaction between underground heating networks and other energy infrastructure. Future research should focus on expanding the numerical model to incorporate transient heat transfer effects and different soil compositions, further improving the accuracy of heat loss predictions.

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