# Real Temperature Distribution on the Surface of Underfloor Heating

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***Abstract*-The article presents the possibilities of developing the heat transfer area of supply pipes in underfloor heating. It examines the influence of ribs shape and the distance between them on the distribution of temperatures on the surface of heating plates depending on the variable temperature of the heating factor. Numerical analyses were conducted for the predetermined steady states and based on the finite element method.**

***Keywords*- Heat Transfer; Rib; Underfloor Heating; Temperature Gradient**

## I. INTRODUCTION

Underfloor heating is a method of room-heating, in which the thermal power transmitted through radiation is higher than the thermal power transmitted through convection. Thanks to the above and advantageous direction of the temperature gradient in terms of thermal comfort, minimum changes in the vertical plane of the room cross-section are achieved. Thus, the highest temperatures are experienced at floor level and the lowest temperatures are experienced at head level.

Pipes are the primary element of underfloor heating. Depending on the selected assembling technology, they are laid in the screed or thermal isolation layer. As a result of observing recommended distances between the pipes (0.1 ÷ 0.3 m), temperature differences appear on the surface of the underfloor heater above the axes of the heating pipes, and in the middle of the distance between them [1]. The differences increase simultaneously with increasing distance between the pipes, thus raising the temperature of the heating medium. In consequence, it is complicated to apply ecological, renewable energy resources. In order to correctly design an underfloor system and to evaluate the total heat loss for a given room, it is necessary either to densely arrange the heating conductors or to increase the temperature of the heating factor. The distribution of temperature on the surface of the heating plate influences the thermal comfort of its users. A temperature that is too high can cause the swelling of feet and general asthenia, which can in turn influence the effectiveness of work or the comfort of rest. Low temperature on the surface of the heating plate may result in low temperatures in the heated area, which also affects the health of its users.

## II. THEORETICAL CONSIDERATIONS

This research employed a concept of ribs, in which a surface of heat exchange in the heating pipes is developed, which leads to increased heat transmitted from the surface of the heating plate and a subsequent lowering of the supply factor temperature.

Numerical research according to the finite element method (Ansys 12 application) involved determining the distribution of temperatures in the horizontal layer of the examined underfloor heater, with and without the presence of ribbed supply pipes. The heating plate model was divided into non-overlapping small elements, which influenced one another through nodes. In the analyses of the heat exchange, the temperature interpolated with the use of polynomials represents the degree of freedom of each node, selected for each element and determined according to nodal temperature values, thus maintaining continuity on the boundaries of the elements. According to the mathematical approach known as the finite-element method, a generalization is applied in which the temperature trajectory is approximated with the use of a trial function, being a finite sum of the function of shape [2].

A fragment of the heating plate together, with marks representing places which register temperature values, is presented in Fig. 1. The model has been slightly modified in the further parts of this research by increasing the heat exchange area of the heating pipes with the use of ribs; the adapted model was then used for further numerical research regarding the plate with ribbed supply pipes [3].



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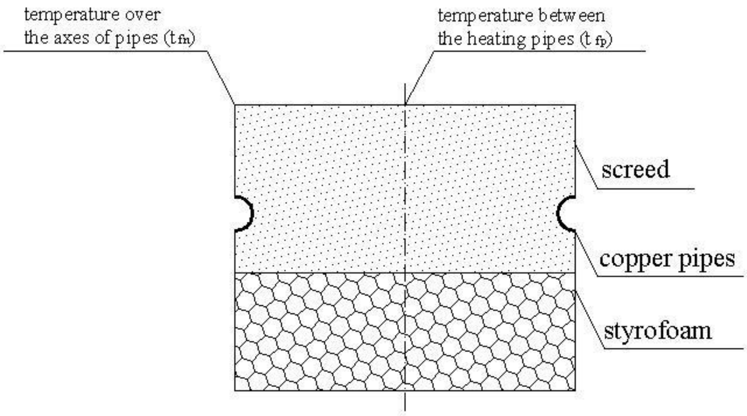


Fig. 1 Fragment of a heating plate

Parameters of particular components of a heating plate:

- screed with a thickness of 0.075 m, thermal conductivity $\lambda_j$ = 1.4 W/(m · K);

- copper pipes DN15x1, thermal conductivity $\lambda_m$ =370 W/(m · K)

- styrofoam of 0.05 m thickness, thermal conductivity $\lambda_s$ = 0.045 W/(m K).

The process of heat exchange between the underfloor heater and the environment was considered assuming constant values for the temperature of supply water in the system and the heat conductivity of the applied materials.

On the external surfaces of the heating plate, the boundary conditions were defined as follows [4]:

- **Type I boundary condition**: under the layer of thermal insulation, a constant temperature value was set to $t_{di}$ = 20°C,

- **Type II boundary condition**: on the vertical external surfaces of the heating plate, a symmetry was assumed so that perpendicular to these surfaces, the temperature gradient and heat flux density reached a "0" value,

- **Type III boundary condition**: on the surfaces of the internal heating pipes, the temperatures equal to the temperatures of the heating factor were applied, i.e., $t_{z1}$ = 30°C, $t_{z2}$ = 35°C, $t_{z3}$ = 40°C. The heat transfer coefficients for the considered surfaces were calculated based on the Nusselt number, determined by the relation:

$$Nu = \frac{h_p \cdot d_w}{\lambda} \tag{1}$$

where:

$h_p$ is the heat transfer coefficient on the inner layer of the pipe wall [W/m$^2$ · K],

$d_w$ is the inner diameter of the heating pipe [m], and

$\lambda$ is the thermal conductivity of heat from the heating medium [W/ m · K]. Physiochemical parameters of water used for the calculations are presented in Table 1.

TABLE 1 PHYSIOCHEMICAL PARAMETERS OF HEATING WATERS DEPENDING ON TEMPERATURE

| **Temperature of heating medium** | **Thermal conductivity** | **Kinematic viscosity** |
|---|---|---|
| $t_z$ °C | $\lambda$ $\frac{W}{m \cdot K}$ | $\nu$ $\frac{m^2}{s}$ |
| **30** | $61.8 \cdot 10^{-2}$ | $0.805 \cdot 10^{-6}$ |
| **35** | $62.6 \cdot 10^{-2}$ | $0.73 \cdot 10^{-6}$ |
| **40** | $63.5 \cdot 10^{-2}$ | $0.659 \cdot 10^{-6}$ |

The Nusselt number is expressed by dimensionless criterion numbers, i.e., the Reynolds and Prandtl numbers: Nu = f (Re, Pr). The Reynolds number was calculated according to the following formula:

$$\mathrm{Re} = \frac{v \cdot d_w}{\upsilon} \tag{2}$$



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where:

$\upsilon$ is the kinematic viscosity of water [$m^2$/s], and

v is the flow rate of the heating medium for the average value: 0.3 m/s, determined based on the (2) Reynolds number and indicating a transitory nature of the heating medium. In order to determine the Nusselt number, the following formula was used [5]:

$$Nu = 0{,}00069 \cdot \mathrm{Re}^{1{,}24} \cdot \mathrm{Pr}^{0{,}5} \tag{3}$$

The above is correct if the following conditions are maintained:

$$2300 \leq \mathrm{Re} < 10000 \text{ and } 0{,}7 < \mathrm{Pr} < 160.$$

Next, according to Formula (1), the heat transfer coefficients on the inner surface of the heating pipe were calculated. The values of the coefficients depend on the temperature of the heating medium, as presented in Table 2.

TABLE 2 HEAT TRANSFER COEFFICIENTS ON THE INNER SURFACE OF THE HEATING PIPE

| **Temperature of heating medium** $t_z$ | **Reynolds number** Re | **Prandtl number** Pr | **Nusselt number** Nu | **Heat transfer coefficient** $h_p$ |
|---|---|---|---|---|
| $^{\circ}C$ | – | – | – | $\frac{W}{m^2 \cdot K}$ |
| **30** | 4844 | 5.42 | 59.65 | 2835.5 |
| **35** | 5327 | 4.81 | 63.22 | 3044.2 |
| **40** | 5918 | 4.31 | 68.17 | 3329.8 |

A boundary condition of the third type was also adopted for the upper surface of the heating plate. The established air temperature in the room was $t_i = 20\,^{\circ}C$.

The total density of the stream of heat emitted from the surface of the heating plate to the environment is represented by the sum of the heat stream exchange via convection and radiation:

$$q = q_k + q_p \quad [W/m^2] \tag{4}$$

The density of the heat stream acquired through convection is defined by Newton's law:

$$q_k = h_k (t_p - t_i) \quad [W/m^2] \tag{5}$$

where:

$t_i$ is the air temperature in a room, in $^{\circ}C$, and

$t_p$ is the average temperature on the upper surface of the heating plate, in $^{\circ}C$

The density of the heat stream acquired through radiation is specified by the following formula:

$$q_p = h_p (t_p - t_i) \quad [W/m^2] \tag{6}$$

The accessible literature [6, 7] provides models for calculating the coefficients of acquiring heat through radiation and convection. In the above numerical analyses of the heating plates, in accordance with the standard PN-EN 1264 - 2:2013, the adopted total value of the coefficient of acquiring heat from the surface of the floor heater was $h_c = 10.8 \frac{W}{m^2 \cdot K}$. This value is constant, regardless of the temperature of the heating factor or the air temperature in the room. The above solution is justified in case of established (static) work of the heating plate, the temperature of which on the external surface is adopted in a quite limited range, whereas in the case of dynamic work of a floor heater the mentioned temperature is established in a much wider range (i.e., from the moment of the plate is switched on (low temperature) up to full efficiency (maximum temperature). The total value of the coefficient of acquiring heat from the surface of the floor heating varies depending on temperature differences between the average value on the plate surface and the average air temperature in a room.

The model of a heating plate used with the boundary conditions is presented in Fig. 2.



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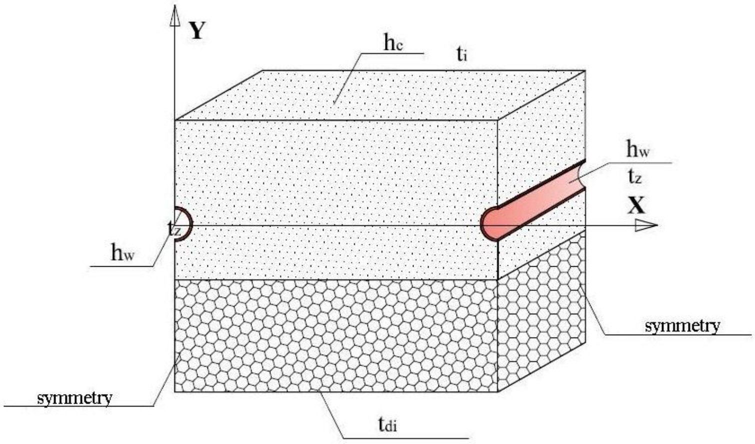


Fig. 2 Boundary conditions

### A. Floor Panel without the Ribbing of the Heating Pipes

In the numerical calculations, a two-dimensional system X−Y and 8−node components (Plane type) from the Ansys 12 application were used. An attempt was undertaken to determine the influence of the distance between the heating pipes (r) on the temperatures of the plate surface. The distances between supply pipes in the range of (r) 0.05 ÷ 0.3 m and values of the heating water temperature ($t_z$), equal to $t_{z1}$ = 30 °C, $t_{z2}$ = 35 °C, $t_{z3}$ = 40 °C were used as variables. The relationships between the enumerated values are presented in the graphs in Figs. 3 - 5.

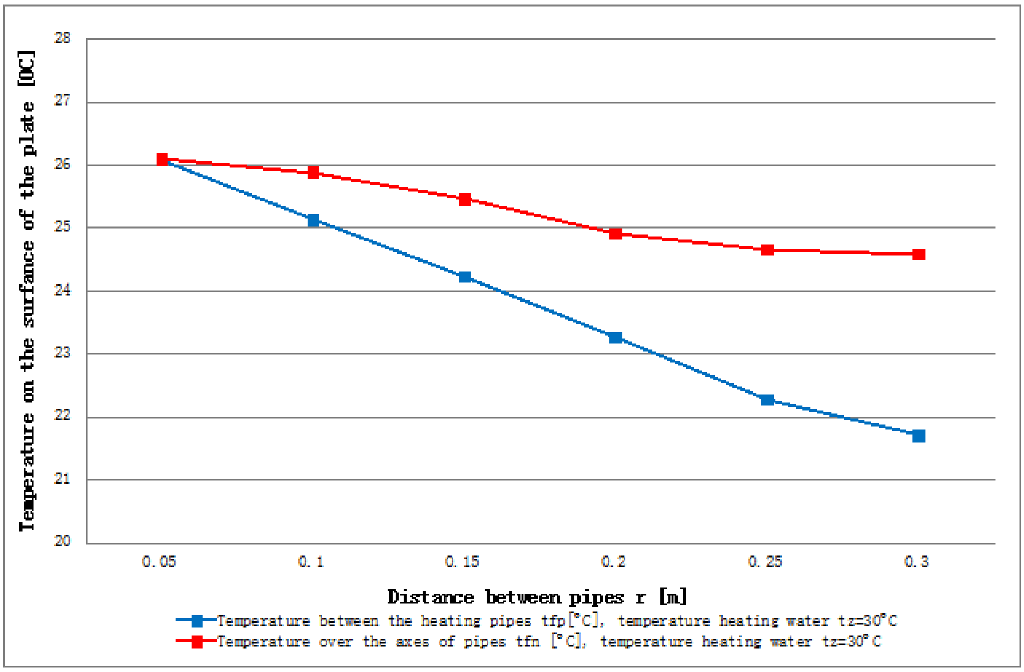


Fig. 3 Influence of changes in distance between the supply pipes (r) on surface temperature of the heating plate when the temperature of the supply medium $t_{z1}$ = 30°C



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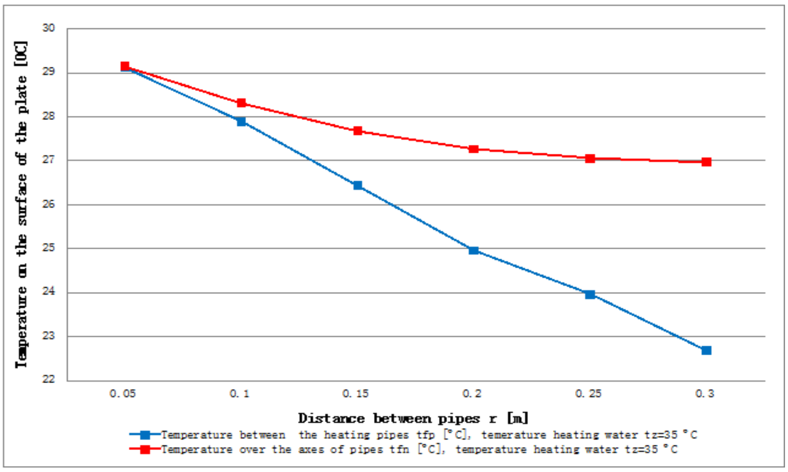


Fig. 4 Influence of changes in distance between the supply pipes (r) on the surface temperature of the heating plate when the temperature of supply medium $t_{z2} = 35^oC$

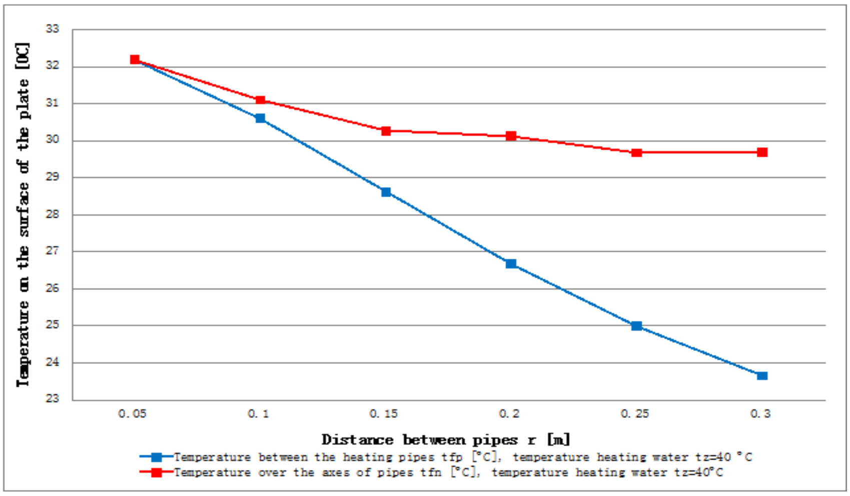


Fig. 5 Influence of changes in distance between the supply pipes (r) on the surface temperature of the heating plate when the temperature of supply medium $t_{z3} = 40^oC$

Numerical analyses of the heating plate without ribbing have proven the relations between the temperature on the upper surface and the temperature of the supply medium ($t_z$). Only with application of the shortest possible distance between the pipes (r = 0.05 m) it is possible to achieve balanced temperature values on the surfaces of the plates. Increasing the distance (r) between the supply pipes embedded in a layer of screed results in lower temperature on the pipe surface above the pipes axes ($t_{fn}$) in a significantly narrow range of approximately $2^oC$, when the heating medium temperature $t_{z1} = 30^oC$; a range of approximately $2.2^oC$ when the heating medium temperature $t_{z2} = 35^oC$; and a range of $3.2^oC$ when the temperature of the heating medium was $t_{z3} = 40^oC$. Alternatively, the drop in temperature between the heating pipes combined with increasing distance (r) is significant, and equals approximately $7^oC$ when the heating medium temperature $t_{z3} = 40^oC$.

Numerical research of underfloor heating without ribbing determined the most disadvantageous distance between heating pipes used in underfloor heating, r = 0.3 m. This distance has been accepted for further analyses of plates with ribbed heating pipes.

### *B. Heating Plate with Circular Ribbing of Supply Pipes*

In this research, a three-dimensional system X-Y-Z and 20-node element array (Solid type) using the Ansys 12 application were introduced. The following values were constant: heating medium temperature $t_{z3} = 40^oC$, inner diameter of rib $d_w = 0{,}015$ m, thickness of ribs $g_ż = 0.002$ m and the thermal conductivity $\lambda_ż = 370$ W/(m · K). The distance between the ribs ($p_o$) and the outer diameter of a rib ($d_z$) took on the following variable values:

− external diameter of the rib ($d_z$): $d_{z1} = 0.026$ m, $d_{z2} = 0.030$ m, $d_{z3} = 0.032$ m, $d_{z4} = 0.034$ m, $d_{z5} = 0.036$ m, $d_{z6} = 0.038$ m, $d_{z7} = 0.040$ m, $d_{z8} = 0.042$ m, $dz_9 = 0.044$ m, $d_{z10} = 0.046$ m,

− distance between the ribs ($p_o$): $p_{o1} = 0.007$ m, $p_{o2} = 0.020$ m.


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The thermogram in Fig. 6 presents the distribution of temperatures in a cross-section of an underfloor heater with heating pipes equipped with circular ribs of external diameter $d_{z1}$ = 0.026 m, and a distance between ribs $p_{o1}$ = 0.007 m.

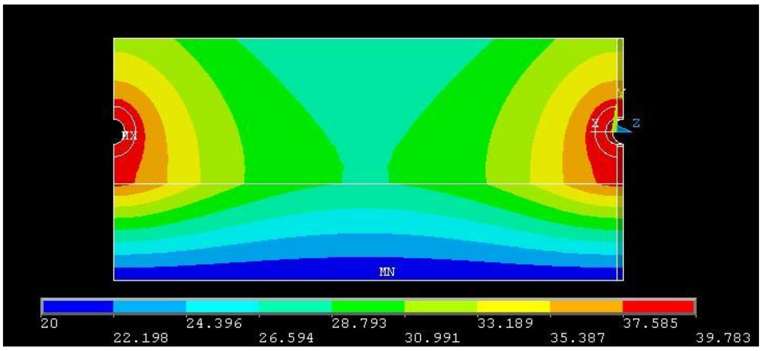


Fig. 6 Temperature distribution in the plate with circular ribs of external diameter $d_{z1}$ = 0.026 m and distance between ribs $p_{o1}$ = 0.007 m

Figs. 7 and 8 depict the relationships between temperatures observed on the ribbed surface of the heating plate over the axes of pipes ($t_{fn}$) and between pipes ($t_{fn}$) depending on the distance between the ribs ($p_o$) and their external diameter ($d_z$).

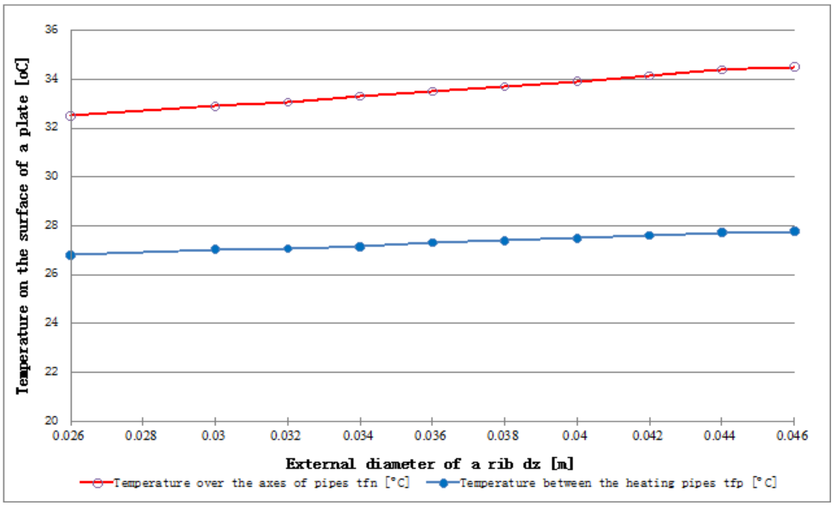


Fig. 7 Influence of changes in external diameter of ribs ($d_z$) on the surface temperature of the heating plate with the distance between ribs $p_{o1}$ = 0.007 m

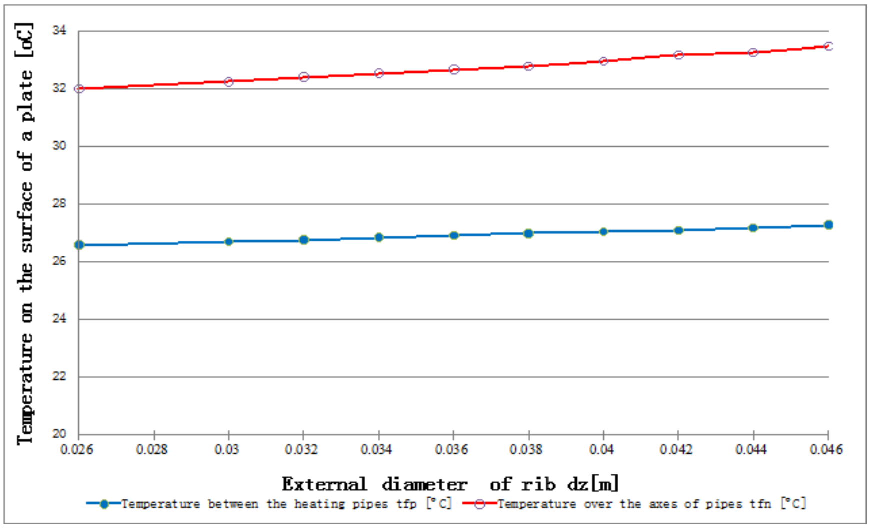


Fig. 8 The influence of changes of external diameter of ribs ($d_z$) on surface temperature of the heating plate with the distance between ribs $p_{o2}$ = 0.02 m

Numerical research of a plate with circular ribbing in heating pipes proved that the applied type of ribbing, regardless of the external diameter of rib ($d_z$) and the distance between the ribs ($p_o$), did not enable balance of temperature on the external surface of the underfloor heater. Regardless of the distances between ribs ($p_o$), increasing the value of external diameter ($d_z$) resulted in increased temperature ($t_{fn}$) over the axes of pipes, reaching 2.5°C. The temperature between the pipes ($t_{fp}$), regardless of the distances between ribs ($p_o$), could be increased only within the limited range of approximately 1°C.



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The analyzed cases of underfloor heating with heating pipes with circular ribs do not obtain uniform values of temperature on the plate surface. The use of circular ribs in the underfloor heating also does not enable lowering the temperature of the heating medium; therefore, from the perspective of improvement of heat exchange conditions between the heating plate and the environment, their use should be regarded as uneconomical.

*C. Heating Plate with Rectangular Ribbing of the Heating Pipes*

In the analyses, a three-dimensional system – X-Y-Z and the 20-node element of Solid type from the grid distribution in Ansys 12 were used. The accepted values for the ribs are presented in Fig. 9.

**Constant values:**

− ribs width s = 0.02 m,

− ribs thickness $g_ż$ = 0.0005 m,

− thermal conductivity of the rib (copper) $\lambda_ż$ = 370.W/(m · K).

**Variable values:**

− temperature of the supply medium ($t_z$): $t_{z1}$ = 30°C, $t_{z2}$ = 35°C, $t_{z3}$ = 40°C,

− distance between the ribs ($p_p$): $p_{p1}$ = 0.01 m, $p_{p2}$ = 0.07 m,

− height of a rib ($H_ż$): $H_{ż1}$ = 0.02 m, $H_{ż2}$ = 0.04 m, $H_{ż3}$ = 0.06 m, $H_{ż4}$ = 0.08 m, $H_{ż5}$ = 0.10 m, $H_{ż6}$ = 0.12 m, $H_{ż7}$ = 0.14 m.

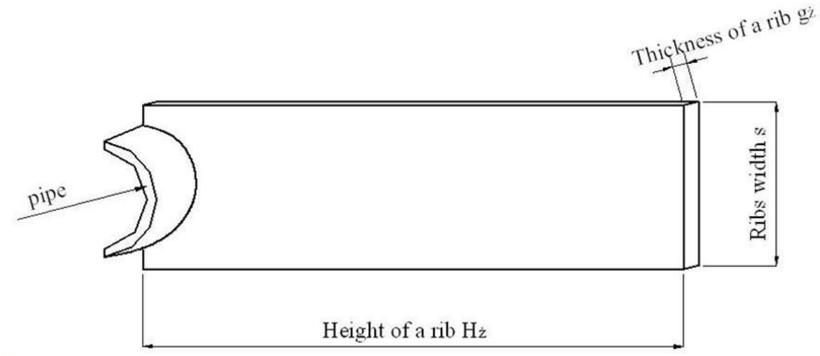


Fig. 9 Marking of the rectangular rib

The thermogram (Fig. 10) presents the distribution of temperatures in a cross-section of a heating plate, obtained via numerical calculations made in the Ansys 12 application for pipes with rectangular ribs, and with the height of ribs $H_{ż5}$ = 0.1 m. The distance between the ribs is $p_{p2}$ = 0.07 m, and the temperature of the heating medium is $t_{z2}$ = 35°C. Rectangular ribs extend the temperature field in the horizontal plane of the considered plate, thus reducing the thermal resistance of the screed, which in turn influences the temperature of the upper surface of the heater.

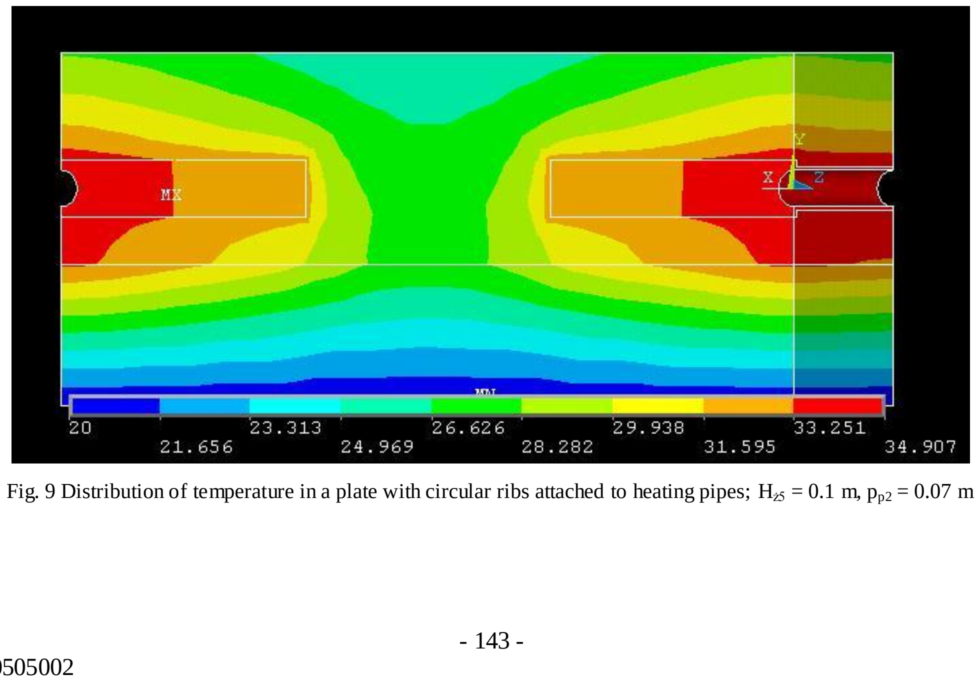


Fig. 9 Distribution of temperature in a plate with circular ribs attached to heating pipes; $H_{ż5}$ = 0.1 m, $p_{p2}$ = 0.07 m



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Figs. 11 and 12 present graphs depicted the influence of ribs height ($H_ż$) and the distance between ribs ($p_p$) on the temperature values observed on the surface of the plate over the axes of the heating pipes ($t_{fn}$) and between them ($t_{fp}$), depending on the temperature of the heating medium ($t_z$).

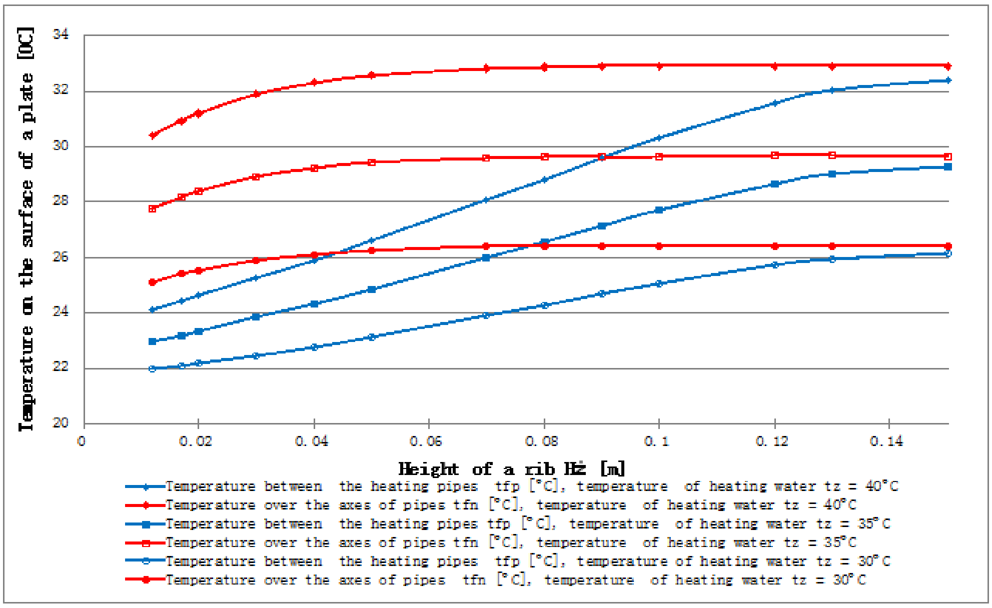


Fig. 11 Influence of changes in the height of rectangular ribs ($H_ż$) on the surface temperature of the heating plate when the distance between the ribs $p_{p1} = 0{,}01$ m

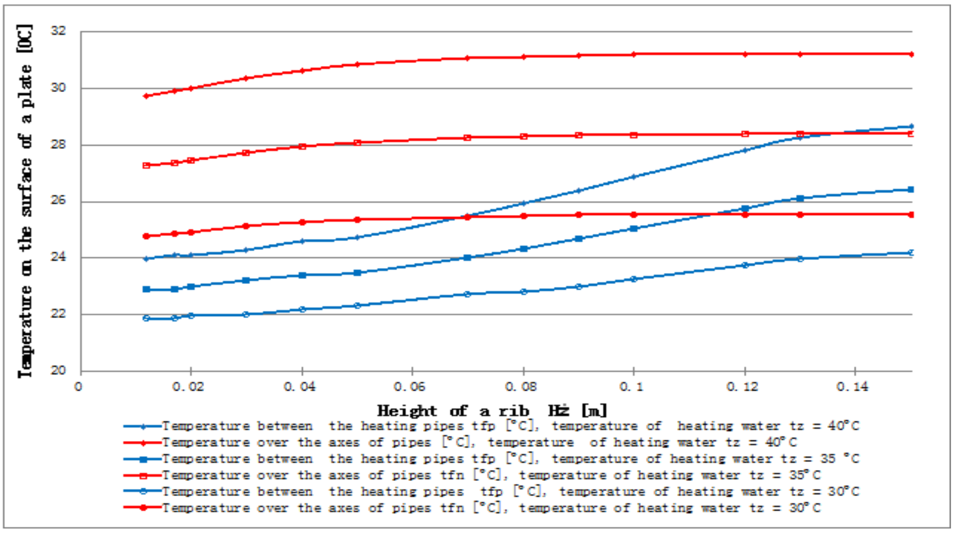


Fig. 12 Influence of changes in the height of rectangular ribs ($H_ż$) on the surface temperature of the heating plate when the distance between the ribs $p_{p2} = 0.07$ m

Analysis of the results obtained from numerical research of an underfloor heater with a developed surface of heating pipes and heat exchange via rectangular ribs have proven the possibility of reducing the temperature difference on the surface of a heating plate. The difference is strictly associated with the height ($H_ż$) and the distance between ribs ($p_p$). Increasing the height of the ribs ($H_ż$) results in a general increase of the temperature on the surface of the plate. For the temperature determined above the axes of the pipes ($t_{fn}$), regardless of distance between the ribs ($p_p$), the temperature increased rapidly, along with increasing height of the rib, up to $H_{ż4} = 0.08$ m. After exceeding this value, a certain stabilization of temperature above the axes of the pipes ($t_{fn}$) was observed. Developing the surface of heat exchange by adding rectangular ribs influences the temperature between the heating pipes ($t_{fp}$), resulting in its successive increase, regardless of the temperature of the supply medium ($t_z$). The analyzed cases of underfloor heater with rectangular ribs attached to the heating pipes indicate that ribs for the purpose of increasing the thermal exchange on the surface of the pipes makes it possible to extend the temperature field in the horizontal plane, thanks to which temperature on the surface of the plate are more uniform and steady.

For the empirical research, copper pipes and rectangular ribs of height $H_{ż4} = 0.08$ m and thickness $g_ż = 0.0005$ m placed at a distance of $p_{p2} = 0.07$ m were utilized.



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## III. EXPERIMENTAL RESEARCH

The test apparatus used for empirical research was developed in the room 044 of the Institute of Environmental Engineering and Building Structures of Lodz University of Technology. A schematic diagram of the test apparatus is presented in Fig. 13.

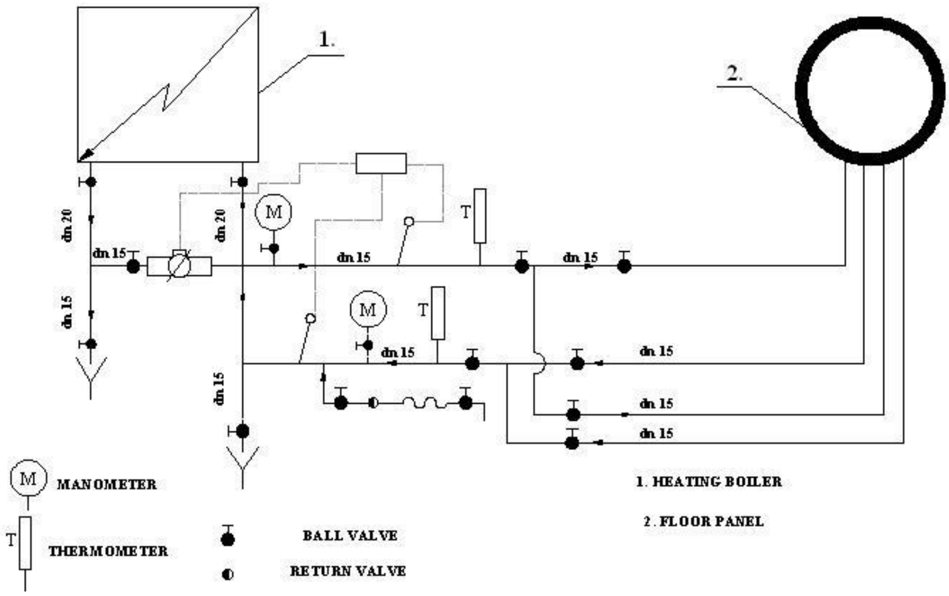


Fig. 13 Test apparatus diagram

The heating plate was attached to the existing ceiling. Copper pipes of 15 mm diameter and 1 mm of the wall. The floor panel consists of two independent parts:

– part A: heating pipes with brazed rectangular ribs,

– part B: heating pipes without ribs.

In both parts (A and B) there is a constant distance between heating pipes, r = 0.3 m. The tested portions of the heater (A and B) were separated from each other with a layer of styrofoam of 0.05 m thickness, and two chipboards of 0.018 m each.

Fig. 14 presents a section of the heating pipes (part A) before being embedded into a layer of screed. The applied ribs were cut from a sheet of 0.5 mm thick copper and were brazed to the supply pipes.

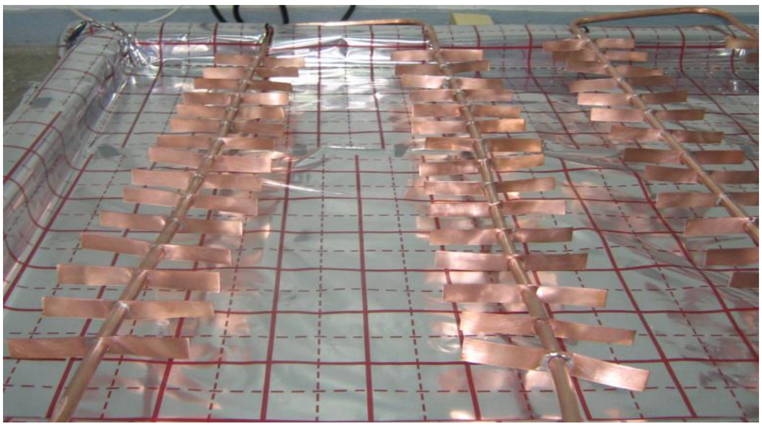

Fig. 14 A fragment of the heating pipes with ribs (plate A) before submerging them in a layer of screed

The test apparatus was designed and built in order to verify the results obtained by theoretical analyses. The following values could be measured at the apparatus:

–volume of the supply medium flow through the heating plate (ultrasonic flowmeter),

--Temperature of supply and return of the heating medium (thermometers, immersion sensors Pt500),

–air temperature in the room,

–temperature at 28 points on the surface of the heating plate (purchased thermocouples T1-T14 and custom-made thermal



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elements T17-T30),

−temperatures at 8 points under the layer of thermal isolation ($T_{izol1} \div T_{izol8}$),

−temperature at 2 points on the external surface of thermal isolation (thermocouples T15 ÷ T16).

Distributions of temperature on the tested surfaces of heating plates and under the layer of thermal insulation were measured with type T thermoelectrical sensors.

Temperature values were measured with electronic meters and sent to a computer. The research was initialized after stabilizing thermal conditions in the room. The temperature of the interior air was equal to $t_i = 20^oC \pm 0.5^oC$.

*A. Accuracy of Measurements*

Type T thermal elements (copper – constantan) representing the accuracy class 1 were used to measure temperature on the surfaces of the A and B plates. According to PN-EN 60584 – 1997 the adjustable deviation of temperature is [8]:

$$\Delta t = \pm 0.5 \text{ K}.$$

An average square error when measuring temperature was calculated according to the following formula:

$$\Delta t = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} \left( t_i - t \right)^2} \tag{7}$$

where:

$t_i$ is the temperature obtained in another measurement [°C],

$t$ is the arithmetic average calculated the value of the measured temperature [°C], and

$n$ is the number of measurements.

Standard deviations of temperature on the surface of the heating plate, calculated according to Formula (7), were included in the range of 0.1 ÷ 0.3 K i.e., they were within the temperature deviation accepted for the utilized class of elements.

*B. Measurement of the Heating Medium Temperature*

To measure the temperature of the heating water, thermo-resistant immersion sensors were used, type Pt500 and in the accuracy class B. In accordance with the accepted standard [9], the acceptable measurement deviation of the sensor was calculated according to the following formula:

$$t = \left(0{,}3 + 0{,}005\ |t|\right) [\,K\,] \tag{8}$$

The measurement error when determining the temperature of the heating water was: $\Delta t = \pm\ 0.5$ K.

An average square error when measuring the temperature of the heating medium ranged between 0.1 and 0.3. Thus, the error did not exceed the absolute error acceptable for class B elements.

*C. Measurement of the Volumetric Flow of the Heating Medium*

A Danfoss ultrasonic heat meter (measurement accuracy class 2) was used to measure the volumetric flow of the heating water. In accordance with the standard [10], the maximum relative error was ±5%.

The relative error when measuring the volumetric flow was calculated according to the following formula:

$$\Delta V = 0{,}05 \cdot V \left[ \frac{l}{h} \right] \tag{9}$$

Thus, for the volumetric flow equal to $V = 143\ \frac{l}{h}$, a relative error when measuring the volumetric flow of the heating medium was $\Delta V = 7{,}5\ \frac{l}{h}$.

The graphs presented in Figs. 15, 16 and 17 depict the temperatures on the surface of the underfloor heater with an increased area of heat exchange for the supply pipes, obtained as a result of numerical and empirical research.



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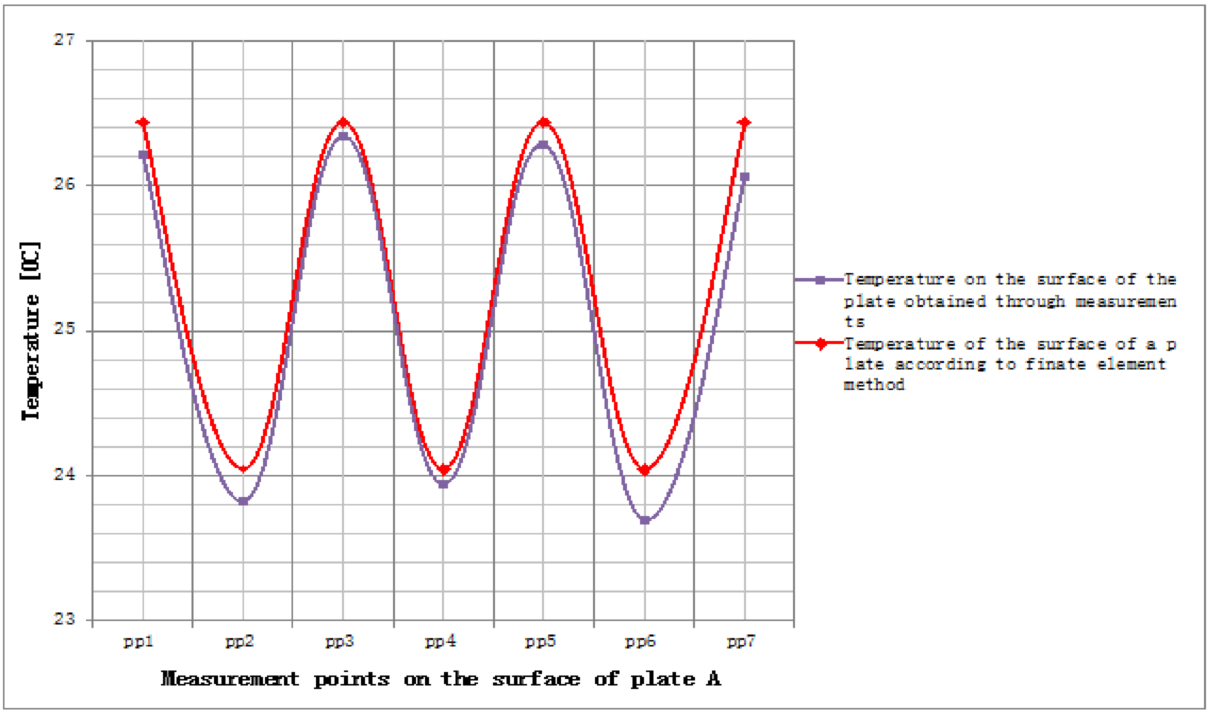


Fig. 15 Summary of numerical results for plate A with empirical values (temperature of the heating medium $t_{z1}$= 30°C)

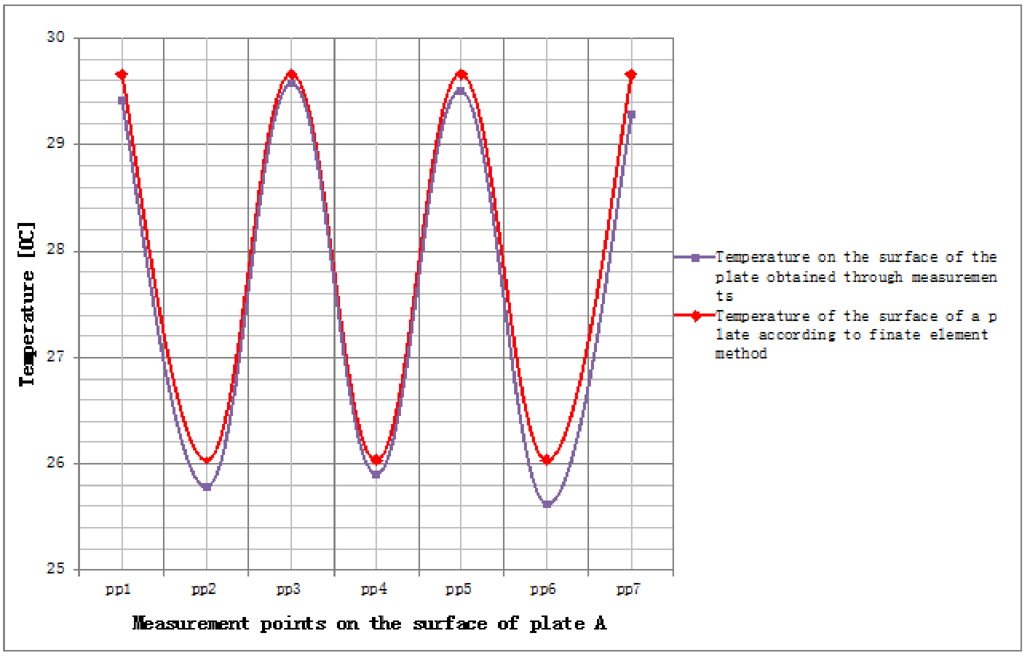


Fig. 16 Summary of numerical results for plate A with empirical values (temperature of the heating medium $t_{z1}$= 35°C)



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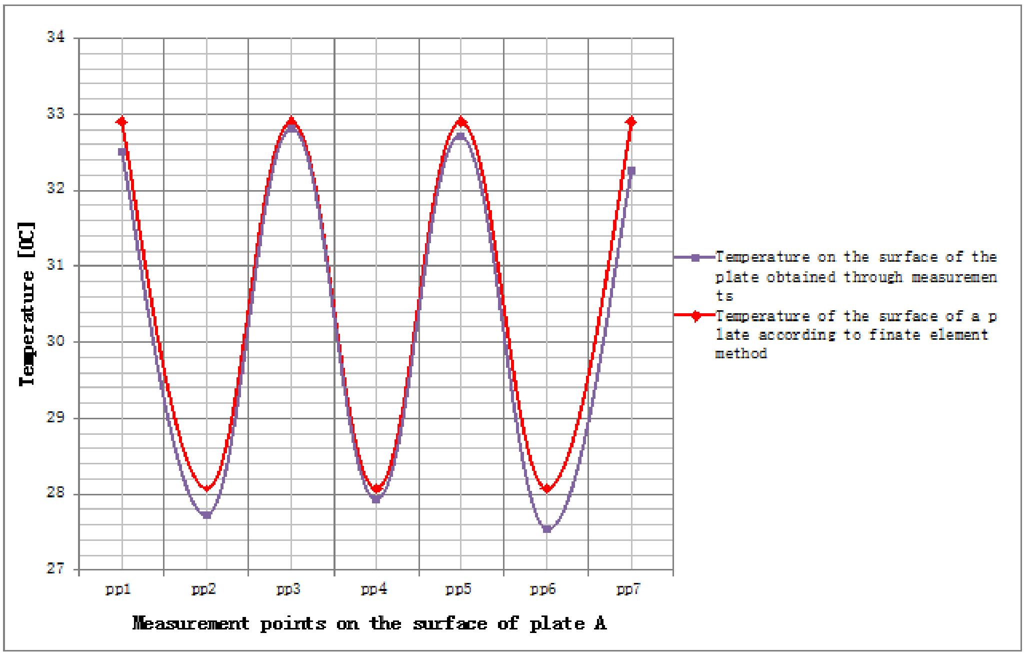


Fig. 17 Summary of numerical results of plate A with empirical values (temperature of the heating medium $t_{z1}$= 40°C)

A convergence of temperature values determined experimentally with the results of numerical analyses was observed in a significant portion of the tested plate containing heating pipes with ribs. Only at extreme points, i.e., at external measurement points, was a lower temperature achieved experimentally than in the corresponding numerical model. Undoubtedly, the reasons for the differences are associated with heterogeneity of screed layer or the method of connecting heating pipes with rectangular ribs and the influence of the environment, which was not taken into consideration in the numerical models.

The positive value of the calculated coefficient of correlation (Table 3) indicates positive correlations between temperature values obtained from numerical analyses and empirical measurements of a plate with heating pipes and rectangular ribs.

The determined values of the correlation coefficient prove a clear relationship between temperatures values obtained in mathematical analyses and measured empirically.

TABLE 3 EMPIRICAL AND NUMERICAL MEASUREMENTS FOR A HEATING PLATE WITH SUPPLY PIPES EQUIPPED WITH RIBS

| **Temperature of the heating medium** | **Correlation coefficient** | **Determination coefficient** |
|---|---|---|
| °C | – | – |
| **30** | 0.995 | 0.991 |
| **35** | 0.998 | 0.996 |
| **40** | 0.996 | 0.993 |

Figs. 18, 19 and 20 present a comparison between the results obtained from experimental and numerical research for the heating plate, depending on the temperature of the supply medium.



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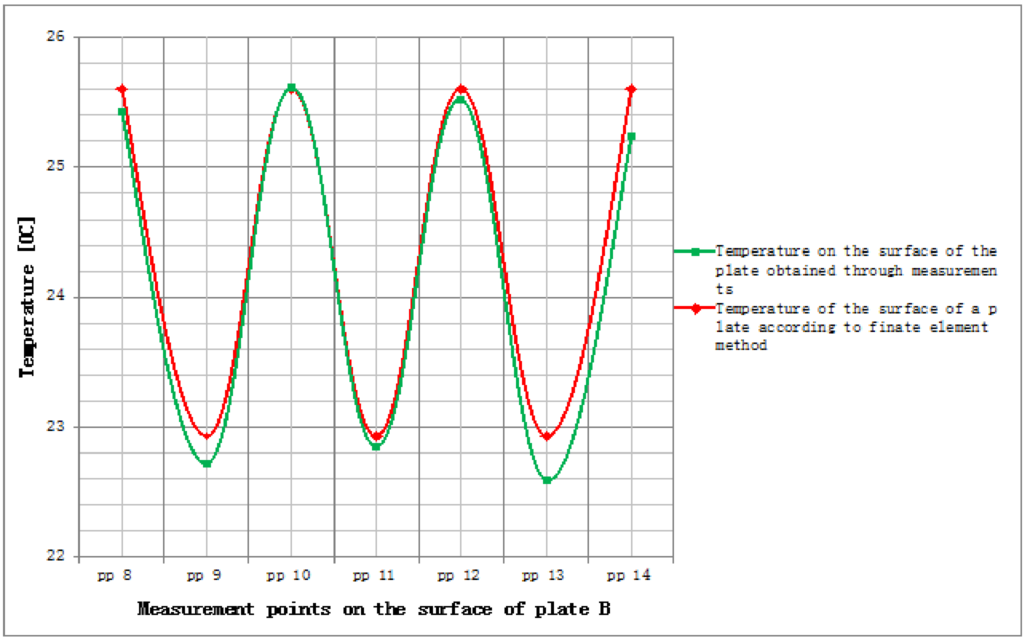


Fig. 18 Numerical results of plate B, with values obtained from empirical research (temperature of the heating medium $t_{z1} = 30^oC$)

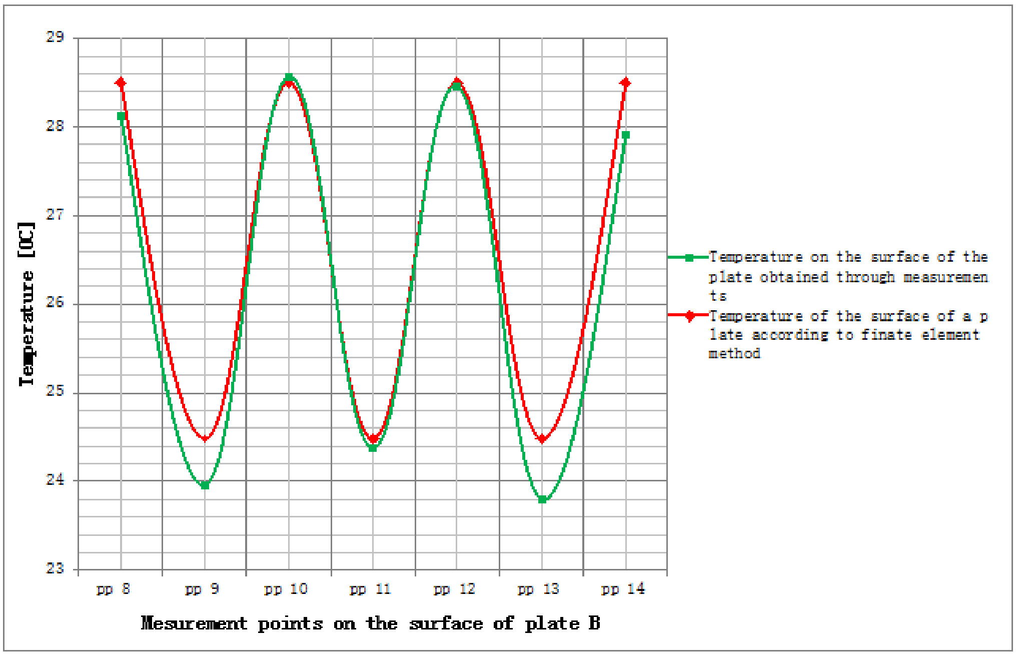


Fig. 19 Numerical results of plate B with values obtained from empirical research (temperature of the heating medium $t_{z2} = 35^oC$)



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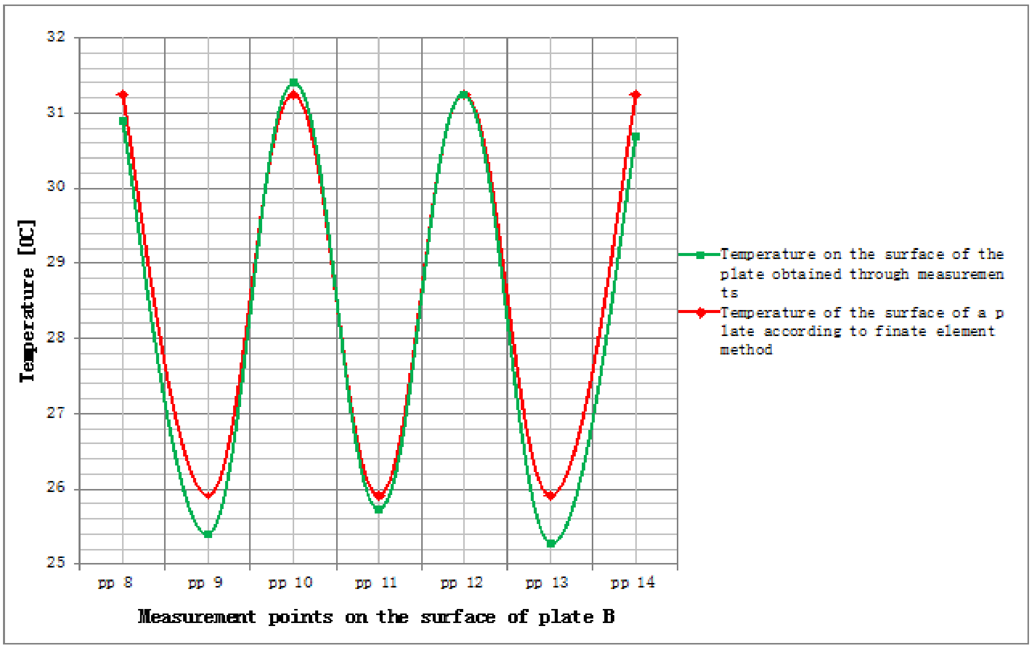


Fig. 20 Numerical results of plate B, with values obtained from empirical research (temperature of the heating medium $t_{z3} = 40^oC$)

Experimental results prove significant convergence with the temperature values obtained from numerical analyses (Table 4 – correlation coefficient $k_B$). The calculated correlation coefficient proves a positive mutual relationship between the considered temperature values.

TABLE 4 EMPIRICAL AND NUMERICAL MEASUREMENTS FOR A HEATING PLATE WITHOUT RIBS AT THE SUPPLY PIPES

| **Temperature of the heating medium** $t_z$ | **Correlation coefficient** $k_A$ | **Determination coefficient** $k_A^2$ |
|---|---|---|
| $^oC$ | – | – |
| **30** | 0.993 | 0.986 |
| **35** | 0.992 | 0.985 |
| **40** | 0.994 | 0.992 |

## IV. CONCLUSIONS

The obtained convergences of experimental results with the numerical results indicate that temperature values determined on the surface of a plate with rectangular ribs on heating pipes depend on the temperature of the supply medium and on the geometrical dimensions of the applied ribs, i.e., on their heights and the distance between them.

The application of circular ribs in order to increase the area of heat exchange in heating pipes in underfloor heating does not equalize the temperature on the external surface of the heating plate in a satisfactory range.

Previous literature also offers other solutions associated with increasing the area of heat exchange of a heating pipe in underfloor heating. It is a common method of heat exchange intensification to place a layer of high heat conductivity over the heating pipes submerged in the layer of concrete. These solutions raise the temperature of the heating plate surface, but do not equalize the temperature value.

The pipes with enlarged surfaces of heat exchange do not equalize the temperature on the external surface of the heating floor. Yet, with their use, the difference in temperature distribution on the surface of a heater above the axes of pipes and in the middle of the distance between them has the approximate value of 2.5 K depending on the temperature of the heating medium. Developing the surface of the heat exchange of the pipes submerged in the screed layer lowers the temperature of the heating medium in floor heating and achieves a temperature which assures thermal comfort on its external surface. Thanks to the low-temperature, renewable energy sources can entirely satisfy needs of the warmth in the given object.



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