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OPTIMIZATION OF CONSTRUCTION PARAMETERS OF A FLOOR CONVECTOR

The paper deals with optimization of construction parameters of a floor convector with natural convection. Intensification of heat transfer from the floor convector with an objective to achieve the highest possible thermal performance of the floor convector was performed by CFD method and criterion equations at boundary conditions, like ambient temperature 20°C and the temperature of the heating medium 75/65°C in thermostatic chamber.

Keywords: Floor convector with natural convection, rib, spacing.

1. Introduction

Floor convectors are heating bodies used in the places where it is necessary to install heaters with a low construction height or where these heaters are to be mounted into the construction of the floor. To achieve the highest possible thermal performances of floor convectors with natural convection with the maximum construction height up to 100 mm some experimental measurements to optimize construction parameters of the floor convector were made in a thermostatic chamber.

2. Construction of a floor convector

The floor convector consists of the following elements: grille (wooden or metal), trim frame and housing. The most important

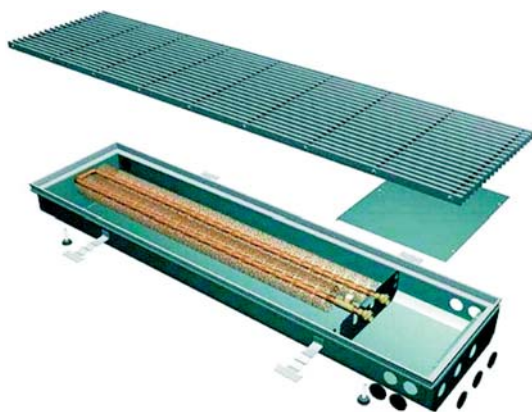


Fig. 1 Part of a floor convector

part is the exchanger placed in the housing. The exchanger is composed of a copper tube with molded aluminum fins to achieve a higher thermal performance. Exchangers usually have matrices with an internal diameter G 1/2" on the one side, and welded air vent on the other side. All this parts we can see at Fig. 1.

3. Heat transfer and floor convectors

The process of heat transfer by the floor convector with natural convection from the heat transfer medium into the ambient air can be divided into (Fig. 2):

1. heat transfer from hot water to the tube wall,
2. heat transfer through the tube wall and heat transfer in the rib (conduction), and
3. heat transfer from the outer tube wall and heat transfer from the rib wall to the air by free convection.

The problem of heat transfer from the floor convector with natural convection can be solved analyzing the basic equations of conservation of (mater, energy, and impulse) and equations of state describing a thermodynamic situation of flowing gas, on the basis of loss calculations for flow, equations of heat transfer and relations for properties of substances. The quantification of thermal flows in real equipment is, owing to the complicated flow fields, most frequently carried out by means of criterion equations.

To simplify and speed up optimization processes, the model of heat transfer from the floor convector with natural convection was constructed on the basis of criterion equations. First of all, the optimal rib spacing at different ribbing heights was looked for to optimize floor convectors with a construction height up to 100 mm. Consequently, the rib thickness enabling the highest performance

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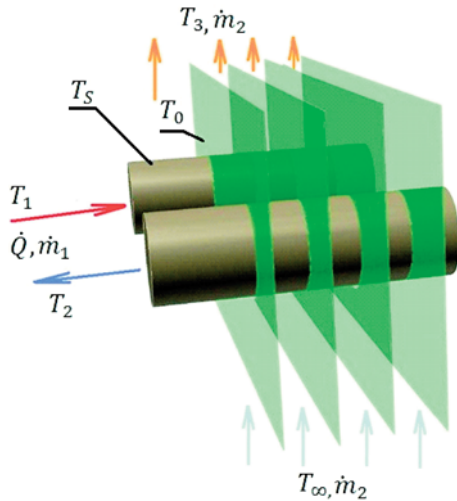


Fig. 2 Heat transfer by a floor convector from the heat transfer medium to the ambient air

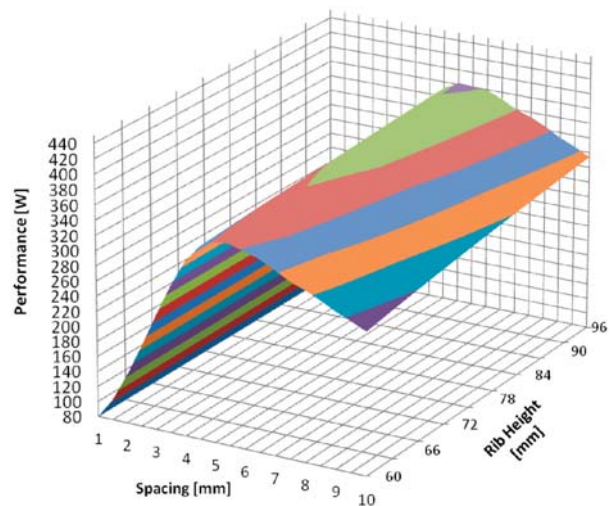
of the floor convector at various rib heights was looked for. As the above mentioned process of heat transfer from the floor convector to the ambient air takes place in the housing of the convector, we also investigated the influence of the housing itself on the floor convector performance.

The optimization itself was performed on a sample of the floor convector having a length of the ribbed surface 740 mm because experimental measurements were also made on floor convectors having the same length, which enabled us to compare and verify the calculation model with real measurements of floor convectors in a thermostatic chamber. The calculation model of the floor convector was set up on the basis of criterion equations of probability theory. This calculation model consists of heat transfer from the heat transfer medium to a tube, of heat transfer through a tube, of heat transfer through a rib and thermal decomposition on a rib by means of Bessel functions, of the calculation of the ribbed surface efficiency, of heat transfer from parallel plates and of heat transfer from a horizontal tube. As the floor convector performance depends on all the above mentioned heat transfers, a mathematical model of the convector was set up from individual sub-processes in Excel. The individual models were interconnected so that the whole calculation could iterate on condition that the heat transferred by forced convection from the heat transfer medium to a tube had to be delivered by the floor convector on the air side by means of natural convection and radiation.

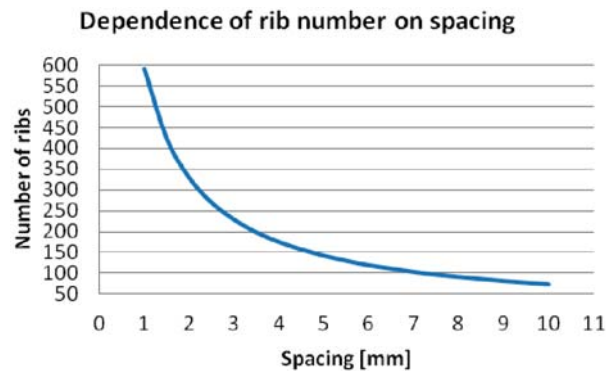
The calculation has to contain boundary conditions such as temperature of the heat transfer medium, ambient temperature, and a diameter of a tube with molded ribs. The convector thermal performance changes with the change in the input parameters. Their influence on the thermal performance can be seen from the following dependences. Criterion equations for individual processes of heat transfer are to be found in [1], [2] and [3].

4. Optimization of construction parameters of a passive floor convector

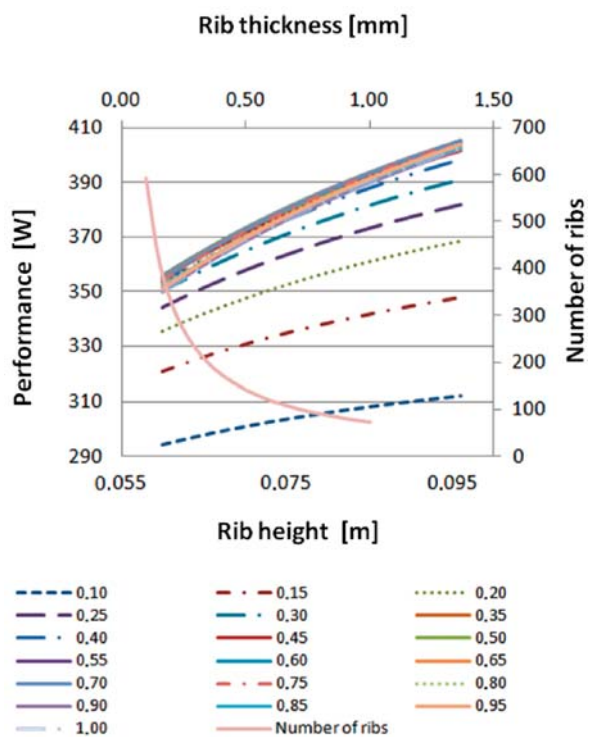
As the performance of a floor convector depends on more construction parameters of the convector it is good to optimize them simultaneously. From these optimizations a 3-D Graph1 was set up. It illustrates the dependence on the spacing and height of a rib at the ambient temperature 20 °C, at the temperature of the heat transfer medium 75/65 °C, pipe diameter 18 mm and at the rib thickness 0.25 mm. This model served for finding the optimal rib spacing at various rib heights to achieve the highest possible thermal performance of the floor convector. From the graphs and calculations it can be seen that the optimal spacing of ribbing at the ambient temperature 20 °C and temperature of heat transfer medium 75/65 °C is 5.5 mm at the rib height 60-100 mm, although according to the analyses of boundary layers a greater spacing is ideal. The use of



Graph 1 Performance of floor convector in dependence on rib spacing and height at the ambient temperature 20 °C, temperature of heat transfer medium 75/65 °C, pipe diameter 18 mm and rib thickness 0.25 mm



Graph 2 Dependence of rib number on spacing of ribbed surface at a ribbing length 740 mm

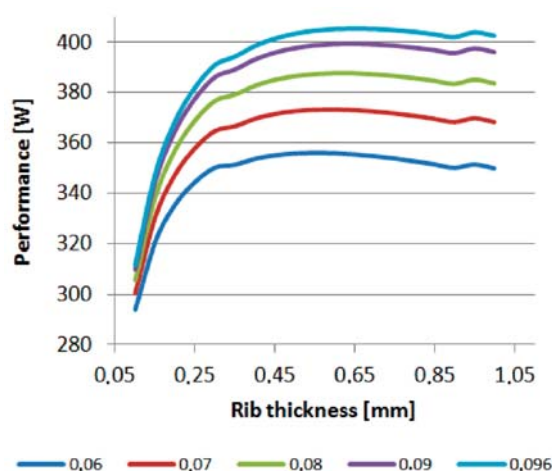


Graph 3 Performance of floor convector in dependence on rib thickness and height at the ambient temperature 20 °C, temperature of heat transfer medium 75/65 °C, pipe diameter 18 mm and at a rib spacing 5.5 mm

greater spacing would result in reduction of heat transfer surface, thus leading to the reduction of the total thermal performance of the floor convector. On the Graph-2 we can see dependence of rib number on spacing of ribbed surface at ribbing length of floor convector 740 mm.

For further increase in the thermal performance of the model floor convector with natural convection, another model was created. The knowledge gathered from previous optimization was used, namely the rib spacing 5.5 mm, which showed to be the most suitable. In this model the dependence of thermal performance on the rib height (60-100 mm) and thickness (Graph3) was modeled. The influence of the rib height and thickness on the total performance of the floor convector can be seen in the graph. The floor convector performance grows with the increasing height of the rib, which is natural as the heat transfer surface also extends. An important finding though is a considerable influence of the rib thickness on the total thermal performance dissipated to the air by means of natural convection, which can be best observed in Graph4. In this graph it is possible to observe a considerable influence of the floor convector rib thickness on the total performance at individual heights of the rib (for better illustration only some performance curves of the model floor convector were chosen), where, for example, at the rib height 60 mm the ideal rib thickness is 0.55 mm (thermal performance 355.9 W); at the rib height 80 mm the ideal

thickness is 0.6 mm (387.52 W) and at the rib height 96 mm it is as many as 0.65 (405.4 W). It is also obvious that further increase in the rib thickness does not result in the increase of performance due to following two reasons: when increasing the rib thickness within the same total length of the ribbed surface, the number of ribs decreases (reduction of heat transfer surface); even if the amount of heat supplied to the rib increases, which results in equalization of the rib temperature, we are unable to dissipate it into the surroundings by means of natural convection.



Graph 4 Floor convector performance in dependence on the rib thickness and height at ambient temperature 20 °C, heat transfer medium temperature 75/65 °C, pipe diameter 22 mm and at a rib spacing 5.5 mm

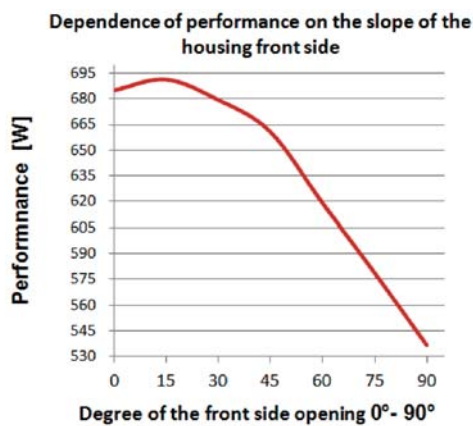
5. Optimization of geometry of the floor convector housing

Experimental measurement for optimization of the floor convector housing and its influence on the performance was made on a sample of the floor convector with the following construction parameters: length of ribbed surface 740 mm, rib height 60 mm, rib length 123 mm, rib thickness 0.25 mm, rib spacing 4 mm and pipe diameter 18 mm. The temperature of heat transfer medium (temperature gradient) was 75/65 °C and temperature of ambient air was 20 °C.

The floor convector was placed in the back part of the thermostatic chamber. An objective of this measurement was to find the most convenient slope of both the front and back sides of the floor convector housing on the performance itself.

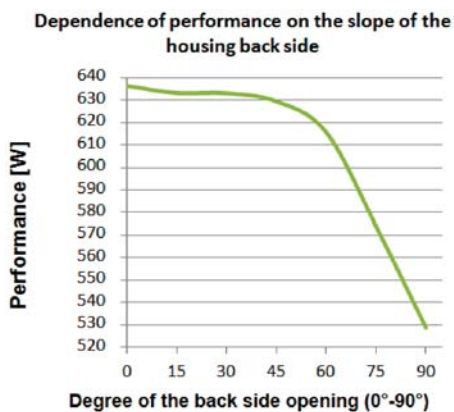
First, we were changing the slope of the front side of the housing starting from 0°, when the front side of the housing was completely open, up to 90°, when it was completely closed. Gradually, the measurements were made for 0°, 15°, 30°, 45°, 60°, 75° and 90° slope of the front side of the housing. From these optimizations

Graph5 illustrating the dependence of the floor convector performance on the slope of the front side of the housing was set up. It can be seen from the graph that at a slope of 0° (when the front side of the convector housing was completely open), the floor convector achieved the highest performance. The convector performance was the lowest at a slope of 90° (the front side of the housing was completely closed).



Graph 5 Dependence of the floor convector performance on the slope of the housing front side

Having completed the changes in the slope of the housing front side, we changed, in a similar way, the slope of the housing back side. It can be seen from Graph6 that similarly as in the case of the slope of the housing front side, the performance of the floor convector is the greatest at the greatest opening (0° slope of the housing) and the lowest at the complete closing (90° slope of the housing). Graph7 illustrates the performance differences at the slope of the front and back sides of the floor convector housing. The difference is due to the fact that at the opening of the back



Graph 6 Dependence of the floor convector performance on the slope of the housing back side

side of the housing the heat transferred to the space washes the back wall of the thermostatic chamber which is cold. Thus the warm air from the convector is mixed with the cold wall and swirls occur, which results in reduction of the thermal performance. The occurrence of whirls can be seen in Fig. 3, in which the floor convector model was created by means of CFD simulation in the program Ansys 12.0. Fig. 3 presents air flow trajectory with velocity contours where the occurrence of swirls can be seen in the wall area of the thermostatic chamber.

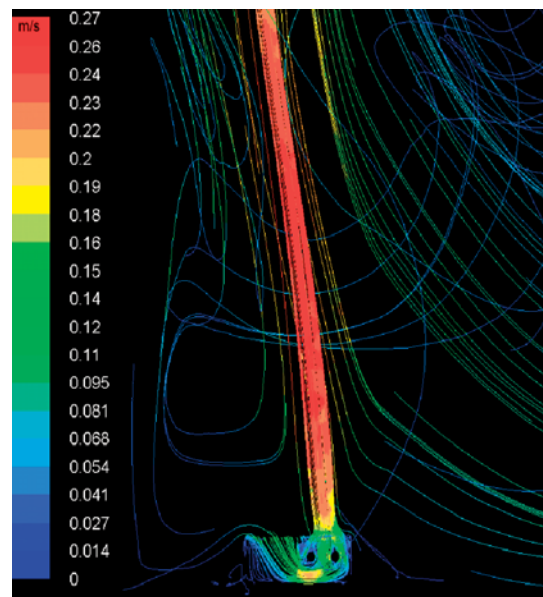
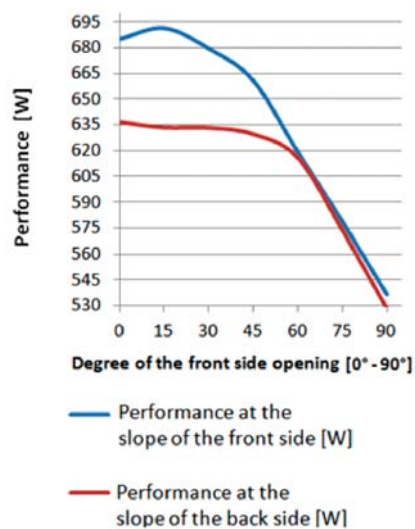


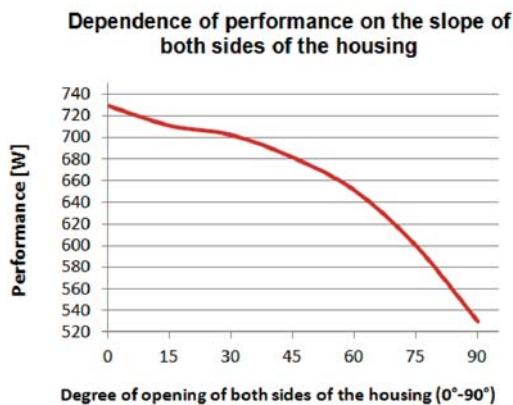
Fig. 3 Air flow trajectory with velocity contours

Dependence of performance on the slope of the housing front and back sides



Graph 7 Comparison of the floor convector performance in dependence on the slope of front and back sides of the housing

The last measurement we made dealt with the influence of the slope of both sides of the housing on the floor convector performance. The slope of the housing sides was changed simultaneously, again in the range from 0° up to 90°. Graph 8 illustrates the dependence of the floor convector performance on the slope of both sides of the housing. From the graph it follows that similarly as in the previous cases, the floor convector performance is the highest



Graph 8 Floor convector performance in dependence of the slope of the housing both sides

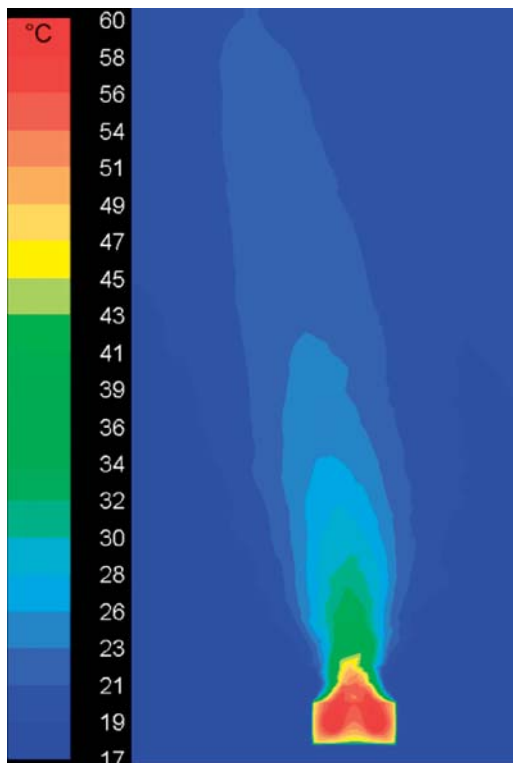


Fig 4 Visualization of thermal field from a sample of a floor convector without housing

at the complete opening of the housing and the lowest at the complete closing of the housing. The influence of the housing on the heat spreading from the floor convector can be compared in Figs. 4 and 5 which present visualizations of thermal fields from the sample of the floor convector made by means of CFD simulations in program Ansys. Comparing the figures we can see a considerable influence of the housing on the flow of air to the surrounding areas [4], [5].

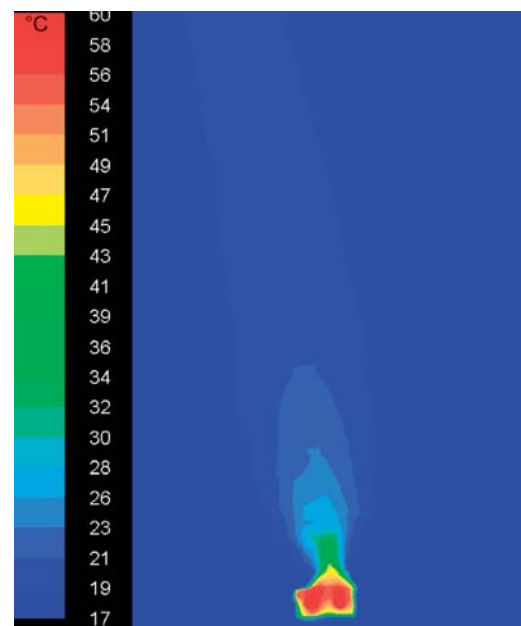


Fig. 5 Visualization of thermal field from a sample of a floor convector with housing

6. Conclusion

From the analysis of individual simulation calculations it can be seen that for the floor convector with natural convection having the ribbed surface length of 740 mm, at temperature gradient 75/65 °C and ambient temperature of 20°C with the tube diameter 18 mm, with the rib length of 123 mm at the rib thickness 0.25 mm (the rib thickness used by a majority of floor convector manufacturers) is the optimal rib spacing 5.5 mm, where at the rib height 60 mm it features the thermal performance 344.395 W, at the height 80 mm it features the performance 368 W and at the rib height 96 mm its thermal performance is 382 W. At further analyses and model creation in dependence of the rib height (60-100 mm) and rib thickness a considerable influence of the rib thickness on the floor convector performance was observed. The performance of modeled floor convector at identical boundary conditions increases with the increasing rib thickness which caused the increase of thermal performance at the rib height of 60 mm up to 355.94 W, at the height 80 mm up to 387.52 W and at the height 96 mm up to 405.44 W at the same lengths of ribbed surface as at the rib

thickness of 0.25 mm. It is also obvious that the performance of a floor convector is, to a certain degree, influenced by the housing geometry. At the complete opening of the front side of the housing the thermal performance achieved 648.88 W, and at the complete closing the thermal performance value was 536.75 W. The thermal performance at the complete opening of the back side of the housing achieved the value 636.38 W and at the complete closing of the back side it achieved the value 528.56 W. At the change of slope of both sides of the housing the thermal performances achieved at

the complete opening the value 729 W and at the complete closing it achieved the value 529.38 W.

It deals with the optimization of geometric shapes of floor convectors at the lowest material and production costs with an objective to achieve their maximal performance parameters.

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