Utility of Boundary Element Method for Modeling Heat Flow in Floor Heating Systems

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ABSTRACT

The phenomenon of heat flow in radiant floors is a complex issue, which consists of mass and heat transfer inside the pipes, heat exchange inside the radiant floor structure and heat transfer from the radiator surface. In order to determine the operating parameters of floor heating systems analytical or semi-analytical methods are primarily used. To solve geometrically more complex constructions numerical methods are used, mainly mesh methods: finite difference method, finite element method and finite volume method. This paper presents the verification of a computer program based on the boundary element method BEM for modelling a steady two-dimensional heat flow in building constructions with floor heating.

The program verification included three stages: verification according to the PN-EN 1264 standard, a comparison with the commercial ANSYS software and experimental tests.

The verification according to the PN-EN 1264 standard consisted in determining the density of the heat flux emitted from the surface of the floor heating and the average temperature of its surface by two methods: BEM program and according to the algorithm presented in the standard. The calculations were carried out for type A of floor heating, which construction and thermal properties are imposed by the standard (Fig. 1). The difference between calculated values of a temperature did not exceed 0.5 K for all analyzed variants. The heat flux density calculated by two methods differed by a maximum of 5% for the pipe spacing ≤ 0,3 m, and by almost 10% for pipe spacing 0,45 m.

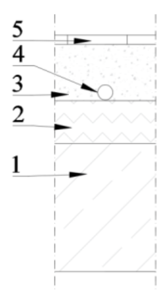

FIGURE 1. Model of floor heating for BEM software verification according to the PN-EN 1264 standard (1 - ceiling, 2 - thermal insulation, 3 - screed, 4 - pipes, 5 - finishing layer)

The second stage of verification involved comparing the calculation results of the BEM program with the calculation results of the software STEADY-STATE THERMAL ANSYS. The analysis concerned four parameters: the density of the heat flux emitted from the bottom and upper surface of the radiant floor and the average values of the temperature at the bottom and upper surface. The calculations were made for a floor heating model presented in the PN-EN 1264 standard (Fig. 1). The assumed maximum temperature error of 0,5 K was not exceeded for all calculation variants for the average temperature at the upper and lower surfaces of the floor heating. Error of the determination of the heat flux density emitted from the bottom and upper surface of the floor heating did not exceed value of 5%.

The last stage of verification of BEM software was the experimental studies. The floor heating construction was made at Bialystok University of Technology, consisting of pipes attached to styrofoam board, laying on concrete and covered with screed (Fig. 2).

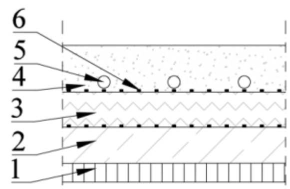

FIGURE 2. Section of a floor heating at experimental stand (1 - furniture board, 2 - B30 concrete with reinforcing mesh, 3 – thermal insulation, 4 - screed, 5 - pipe, 6 - temperature sensor)

At experimental stand the measurements and calculations of four parameters were performed: the average temperature at bottom surface of styrofoam (upper surface of concrete), the average temperature at the upper surface of styrofoam (below and between the pipes), the average temperature at the screed surface and the heat flux density emitted from the upper surface of the floor heating. The measurements were carried out for the variable flow and temperature of the heating medium, corresponding to the commonly used operating parameters of the underfloor heating. The statistics of compliance of measured and calculated values were determined. Acceptable values of the absolute temperature error (0,5 K) and relative heat flux error (5%) were not exceeded for all operational parameters of the floor heating occurred during experiment.

The performed verification with three methods showed that the program using the boundary element method BEM is effective and can be used to model heat transfer phenomena in building constructions with surface heating systems in the scope of determining their operating parameters such as thermal efficiency and surface temperature.

Acknowledgements

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