Statistical analysis as approach to conductive heat transfer modelling

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Abstract. The main inspiration for article was the problem of high investment into installation of the building insulation. The question of its effectiveness and reliability also after the period of 10 or 15 years was the topic of the international research project carried out at the University of Prešov in Prešov and Vienna University of Technology entitled “Detection and Management of Risk Processes in Building Insulation” and numbered SRDA SK-AT-0008-10. To detect especially the moisture problem as risk process in the space between the wall and insulation led to construction new measuring equipment to test the moisture and temperature without the insulation destruction and this way to describe real situation in old buildings too. The further investigation allowed us to analyse the range of data in the amount of 1680 measurements and express conductive heat transfer using the methods of statistical analysis. Modelling comprises relationships of the environment properties inside the building, in the space between the wall and insulation and in ambient surrounding of the building. Radial distribution function also characterizes the connection of the temperature differences.

1. Introduction
To save energy especially during winter time of energy consuming heating systems is the main role of building insulation. Decision making for the proper material with reliable quality also after the period of 20 years can satisfy the high investment during the insulation construction. Suitable insulation property and prevention the case of high moisture level that can cost not only material destruction but also together with the condensation process the suitable environment for microorganisms especially in the space between the building wall and insulation means proper technology of both material and construction.

Regarding the heat transfer reliability important role play conduction, radiation and convention. Internal convective heat transfer modelling is usually expressed through convention coefficient of correlation using building simulation program [6], using the ESP-r [3] with the stress on internal building surface. Improving the modeling of surface convection during natural night ventilation in Building Energy Simulation Models [4] and model with numerous channels both parallel and perpendicular using fibrous porous material [9] try to predict effective thermal conductivity. The prediction results from the suggested models are compared with theory and experimental data.
Sensitivity analysis of heat transfer formulations for insulated structural steel components [8] are based mostly on laboratory testing. Experimental is also optimal design of a photothermal radiometry method [2] using a crenel heating excitation for determination of the effective thermal conductivity. Numerical method, such as Gauss-Newton method and least squares objective function are used for optimization. Surfaces behavior of radiative exchange with the reflection from ideal dielectric surfaces to optical behavior of real surfaces is investigated [5] while thermal radiation is expressed both graphical view and analytical form with the stress on emission from gases, solids and liquids with absorption mechanisms.

Figure 1. Scheme of the measuring equipment for testing both humidity and temperature values in the space between the wall and insulation.
Effect of moisture and porosity on the thermal conductivity and thermal diffusivity of a conventional refractory concrete is tested [7] using the hot wire parallel technique. Experimental results showed a drastic influence of the moisture content on material. The author focuses primarily on thermal conductivity, thermal diffusivity and specific heat up to 1000°C.

2. Measurement series description

Building insulation was tested using new equipment from January 17, 2012 to February 28, 2012 every half an hour. The used measuring equipment for testing, which is expressed in Figure 1, allows also detection the humidity level and temperature between wall and insulation without destruction using the humidity and temperature sensor SHT 15. Another temperature sensor was placed close to the insulation outside the building not to touch surface and not to be far from the surface, so that it is not influenced by the conditions of outside environment. More detailed description of measuring equipment and the testing process is given in Antonyová, Antony [1].

The set of more than 1680 data allowed presenting the graphical representation of the situation regarding the possibility of condensation as risk process in the space between wall and insulation using the calculation for dew point value.

The tested building with the walls made of bricks is heated regularly on the temperature 20°C with polystyrene insulation of the thickness of 8centimetres. The experimental and calculated results proved that there is no danger of condensation process that is one of the conditions for the attack by microorganisms. Insulation made of polystyrene does not absorb water in comparison with for instance natural materials that are intensive water absorbent what highly influences their insulation properties. On the other hand if there is once the water between the wall and polystyrene it remains and can cost serious problems. Water can get there for instance through the holes for electric wires or during the flooding.

3. Conductive heat transfer performance

The temperature values which were obtained experimentally allow describing the process of conductive heat transfer for polystyrene insulation of 8centimetres. Conductive heat transfer is expressed by Fourier’s Law (1).

\[ \frac{q}{A} = k \frac{dT}{s} \]  

where:
\[ \frac{q}{A} \] … heat transfer per unit area (W/m²)
\[ k \] … thermal conductivity (W/m.K)
\[ dT \] … temperature difference between: the temperature in the space between the wall and insulation and temperature in ambient surrounding of the building (°C)
\[ s \] … polystyrene panel thickness (m).

Taking into account the conditions of experimental testing when the polystyrene panels which were used as the insulating material on building envelope are with the thickness of 8centimeters and the value of thermal conductivity for polystyrene is approximately 0.03 W/m.K we get the following expression:

\[ \frac{q}{A} = 0.03 \cdot \frac{dT}{0.08} \]  

The equation (2) is the basement for graphical representation in Figure 2 with modelling the conductive heat transfer.
4. Statistical analysis

Conductive heat transfer between the surrounding inside the building and ambient surrounding of the building expresses equation (3) with its graphical representation in Figure 3.

\[
\frac{q}{A} = \frac{T_l - T_n}{s_1/k_1 + s_2/k_2} \tag{3}
\]

where:

- \( q \) … heat transfer per unit area (W/m\(^2\)),
- \( T_l \) … temperature inside the building that is 20\(^\circ\)C,
- \( T_n \) … temperature in ambient surrounding of the building (\(^\circ\)C),
- \( s_1 \) … thickness of building wall …. 0.4m,
- \( s_2 \) … thickness of polystyrene panel … 0.08m,
- \( k_1 \) … thermal conductivity for bricks that is approximately 0.18 W/m.K,
- \( k_2 \) … thermal conductivity for polystyrene that is approximately 0.03 W/m.K.

We did not take into account air in the space between the wall and polystyrene in formula (3) as the space is very narrow and in some places the materials of wall envelope and polystyrene even touch one another. The relationship is expressed also using the least square by the polynomial of the 6\(^{th}\) degree with the coefficient of determination in Figure 3.

![Figure 2. Graphical representation of modelling the conductive heat transfer through polystyrene with thickness of 8centimetres.](image)
The next Figure 4 expresses the graphical representation of radial distribution function for the relationship between the temperature values in the space between the wall and insulation and in ambient surrounding of the building.
5. Appendices
Conductive heat transfer was studied both experimentally and through statistical analysis. Experiment was carried out using the new technology with the measuring equipment which enables testing the humidity and temperature not only outside the building but also in the space between the wall and insulation. Polystyrene in the form of panels with thickness of 8 centimeters was investigated as a sample of porous material.

Model comprises graphical representations of conductive heat transfer between inside the building and ambient surrounding of the building. The tested building is heated regularly on 20°C. The relationship was expressed also analytic way through the statistical method using the least square by the polynomial of the 6th degree with the coefficient of determination.

Statistical analysis comprises also radial distribution function for the relationship between the temperature values in the space between the wall and insulation and in ambient surrounding of the building.

6. References
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