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Abstract of doctoral dissertation titled:

„Development and application of a non-equilibrium heat, air and moisture transport model in porous building materials"

According to Eurostat statistics, in 2020, approximately 14.8% of the European Union population experienced excessive moisture problems ranging from leaking roofs through damp walls to rot in the apartment. Such buildings require renovation and modernization, often including drying the walls and protecting them against water return. The drying process is not only time-consuming but also energy-intensive. Theoretically, evaporating a kilogram of water requires 0.7 kWh of energy, while the measured energy demand reaches about 2 kWh per kilogram of moisture.

Unfortunately, little research has been conducted to optimize the building drying process. Scientific works focus on experiments in controlled laboratory conditions or in-situ monitoring of building dehumidification. There is a lack of numerical simulations that would allow to optimize the process. Modeling the drying of building materials is based on the hygric equilibrium approach. The approach assumes evaporation or condensation at a very high rate, due to which the saturation parameters are achieved in the material almost immediately. Non-equilibrium heat and moisture transfer modeling during drying has not been used so far.

This work focuses on the numerical study of the drying process of building materials. A non-equilibrium model of heat and moisture transfer in building materials was formulated as part of the doctoral thesis. The model was implemented in the ANSYS Fluent environment using advanced user customization interfaces such as User-Defined Function (UDF), User-Defined Scalar (UDS), and User-Defined Memory (UDM). The software served as a platform for solving the derived transport equations. Without the usage of the customization interfaces (UDF, UDS, UDM), default models implemented in the software do not allow simulation of the drying process. Then, the model was verified using two equilibrium models.

The proposed model was used to simulate the drying process of a building wall part using the thermo-injection method. Two-dimensional simulations of the drying process lasting one week were carried out. According to the meteorological data for Warsaw, the simulations were carried out for a humid ratio in the drying air corresponding to the seasons, i.e., winter, spring, summer, and autumn. Six drying air temperatures constant during simulations, i.e., 20, 30, 40, 50, and 60°C, were analyzed for each season. In the initial drying stage, the energy consumption of the process for an air temperature of 20°C was the lowest. However, a higher temperature was required to reach lower moisture content in the wall. The most significant difference between temperatures for the same season was for winter and the smallest for summer. This is due to the lower moisture content in the air for winter compared to summer and more effective drying at low temperatures.

The next stage of the research involved simulations for time-dependent drying air temperatures during the drying process. Four drying strategies were compared, i.e., single-phase – a strategy with a constant air temperature (60°C); two-phase – drying is first carried out at a low air temperature (20°C) and after a given time at a high temperature (60°C); multi-phase strategy – the process is initially carried out at a low temperature (20°C), and after a given time the temperature is increased by 10 K until it reaches

60°C; periodic strategy – drying is carried out alternately with air at 20°C and 60°C, with a given time of parameter change. Simulations were carried out for relative humidity corresponding to three seasons, i.e., winter, spring, and summer, and for three times of parameter change, i.e., 12, 24, and 48 h, for a process lasting two weeks. The results showed the possibility of reducing the energy consumption of drying using a time-dependent air temperature profile. The highest energy savings, reaching up to 5.9%, were obtained for winter using a multi-phase strategy with a time step of 48 h. The multi-phase strategy for winter and spring gave better results than the two-phase one. A longer time of changing parameters had a positive effect on energy savings. For summer, energy savings were minimal, about 0.5%. The periodic strategy did not allow for improving the efficiency of the process. The company SILTEN POLSKA sp. z o.o. sp. k. applied the proposed two-phase strategy to its drying technology.

Finally, the heat and moisture transfer model in building materials was improved. Air transport in the material was taken into account. An experimental stand was designed and constructed to validate the model. Measurements were taken on a cuboid sample made of aerated concrete with a base dimension of 92 mm by 92 mm and a height of 30.5 mm, saturated with water. The experiment lasted 24 h. A good agreement was achieved between the calculations and the measurement in the initial phase of the process. Similar temperature values were obtained for the first 6 h and similar mass losses for the first 12 h. The simulated temperature was lower than the measured one for a longer time, and the mass loss was greater.

Keywords: masonry wall drying, heat and moisture transfer, non-equilibrium model, numerical calculations

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Doctoral Candidate's Signature