Initial Credibility Analysis of Numerical Model of Heat and Moisture Transfer in Porous Building Materials

Michał Wasik[1, a)] Łukasz Cieślikiewicz[1, b)] Piotr Łapka[1, c)] Piotr Furmański[1, d)]
Michał Kubiś[1, e)] Mirosław Seredyński[1, f)] Karol Pietrak[1, g)]
Tomasz S. Wiśniewski[1, h)] and Maciej Jaworski[1, i)]

[1]Institute of Heat Engineering, Faculty of Power and Aeronautical Engineering, Warsaw University of Technology,
Nowowiejska St. 21/25, 00-665 Warsaw, Poland.
a) Corresponding author: michal.wasik@itc.pw.edu.pl
b) lukasz.cieslikiewicz@itc.pw.edu.pl
c) piotr.lapka@itc.pw.edu.pl
d) piotr.furmanski@itc.pw.edu.pl
e) michal.kubis@itc.pw.edu.pl
f) miroslaw.seredynski@itc.pw.edu.pl
g) karol.pietrak@itc.pw.edu.pl
h) tomasz.wisniewski@itc.pw.edu.pl
i) macjej.jaworski@itc.pw.edu.pl

Abstract. Problems with presence of excessive moisture in masonry walls and building foundations are found very often. Rising damp results in degeneration of properties of insulations and building materials. Moreover, presence of water in the masonry walls may lead to growth of mildew and microorganisms which cause health problems of the occupants. Therefore, many methods of drying of walls and then guarding them from water re-penetration were developed. The creation of waterproof membrane inside the dried wall is one of ways of protection the masonry walls against the moisture. In this method special liquid mixture is injected through several borehole in the wall and then penetrates building material and creates membrane. This technique is effective and durable. However, the quality of waterproof membrane depends on the mixture penetration which is strongly connected to temperature and dryness of the wall, i.e., the higher wall temperature (but not higher than 60°C) and the lower water content the better membrane is obtained. On the other hand, obtaining of these conditions requires significant amount of energy for heating and drying process. Therefore, to increase both energetic and membrane formation efficiencies of this method heating and drying processes of the masonry walls should be optimized. The development of advanced and reliable mathematical and numerical models of heat and moisture transfer in the building materials are the first step that should be undertaken in the optimization process.

The presented mathematical model assumed building material to be hygroscopic porous media filled by moist air and liquid water. Three phases were considered, i.e., solid material, liquid phase (free liquid water) and gas phase (moist air). The bounded water (adsorbed at the surface at the solid component) was neglected. The system of governing equations consisted of four balance equations, i.e., the water vapour mass conservation equation, the dry air mass conservation equation, the liquid water mass conservation equation and the energy conservation equation. Free liquid water was assumed to occur either in a discontinuous motionless form (funicular form) or in a continuous mobile one (pendular form), which moved due to capillary force. The water vapour amount in the building material changed due to diffusion in the pores as well as evaporation and condensation while the liquid water amount varied due to evaporation and condensation as well as the capillary transport. The vapour convection in the porous material was neglected.

Development of the numerical model consisted of three steps, i.e., generation of the computational geometry, generation of the mesh and implementation of the governing equations in the commercial software. The numerical model was developed in the ANSYS CFD environment. The geometry and mesh were created in the ANSYS SpaceClaim and ANSYS Meshing, respectively, while the mathematical model was implemented, and simulations were carried out in the ANSYS Fluent. Advanced customization functionalities like the User-Defined Functions, User-Defined Scalar and User-Defined Memory were applied to implement the system of governing equations. The computational domain was prepared in relation

to the experimental stand which was developed parallel to modeling task – see Fig. 1 and 2. The experiment stand was built with the closed loop – see Fig. 2 – and with controlled temperature, humidity and air velocity. The stand was prepared in order to validate the proposed model. The basic dimensions of computational domain and assumed boundary conditions are also presented in Fig. 1. The computational domain consists of a part of a duct at the top through which dry air is flowing and of a wet material at the bottom as shown in Fig. 1. Due to symmetry only a half of the duct and sample were considered. Subsequently, applying the sweep method the structural mesh with over 3.6 million of elements was generated. For the air region the grid was refined close to walls of the channel and to contact surface between the air and moist brick as well as in the region which refers to walls of the brick.

The numerical model was applied to simulate heating and drying process of brick. Two cases were analyzed: without capillary force transport of liquid water in the brick and with capillary force transport. The numerical predictions were compared with experimental results obtained on the experimental stand for the same heating and drying conditions. Wide range of velocity, temperature and humidity were tested. Satisfactory agreement of the simulated and measured data were obtained.

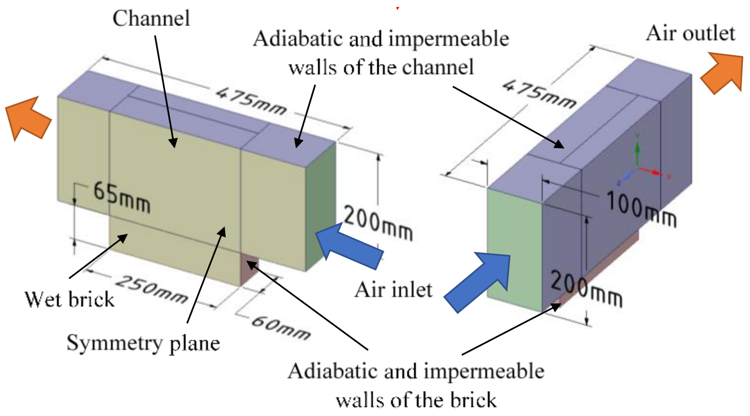

FIGURE 1. Computational geometry with basic dimensions and boundary conditions.

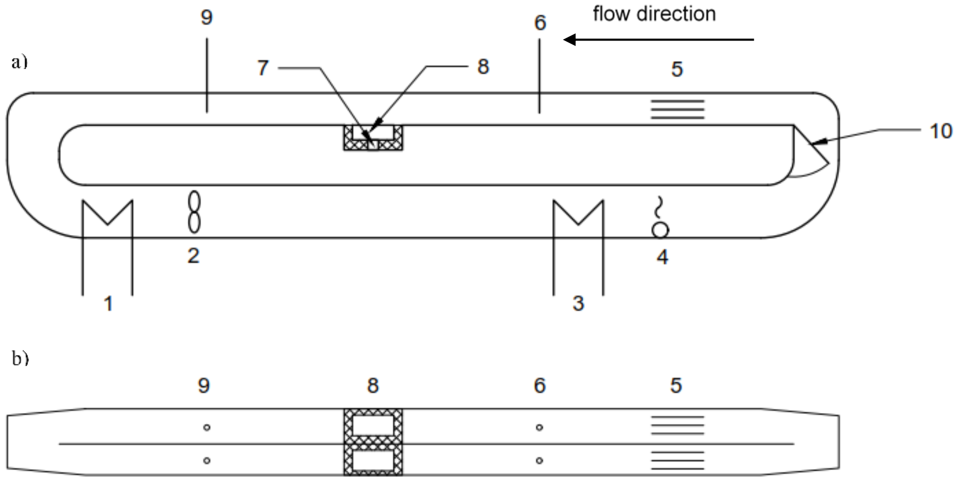

FIGURE 2. Simplified schematic of the closed-loop flow experimental stand: a) side and b) top view (1 – cooler/condenser, 2 – fan, 3 – heater, 4 – humidifier, 5 – flow stabilizer, 6 – integrated velocity, temperature and humidity transmitter, 7 – force meter, 8 – sample, 9 – integrated temperature and humidity transmitter, 10 – throttle).

ACKNOWLEDGMENTS

This work was supported by the National Centre for Research and Development (Poland) under grant no. POIR.04.01.02-00-0099/16 Development of innovative technology of drying and moisture sealing of masonry walls, DryWall and the statutory funds of Faculty of Power and Aeronautical Engineering of Warsaw University of Technology.