INVERSE MODELING OF THERMAL AND HYGRIC PROPERTIES OF BUILDING MATERIALS BASED ON A SEMI-SCALE EXPERIMENT

Zbyšek Pavlík, Jiří Maděra, Robert Černý

Czech Technical University, Faculty of Civil Engineering, Department of Structural Mechanics, Thákurova 7, 166 29 Praha 6, Czech Republic
Email: pavlikz@fsv.cvut.cz, madera@fsv.cvut.cz, cernyr@fsv.cvut.cz

Abstract
A semi-scale experimental analysis of hygrothermal performance of a building envelope in the conditions of difference climate is performed to support computational modeling of heat and moisture transport in climatically loaded building structures. A computational analysis of the same envelope is done using the computer code Delphin 4.3, and the calculated data are compared with the measurements. The observed differences are discussed and recommendations for the improvement of computer modeling process are given.

Key words: hygrothermal performance, building envelope, difference climate conditions, computational analysis

1 Introduction

Mathematical models of heat and moisture transport are very effective tools in the prediction of hygrothermal performance of building envelopes, which are frequently used in envelope design at present. However, any model can provide reliable information only in the case that the quality of input data is very good. This is not always true, because the standard lists of thermal and hygric parameters are usually far for complete and they often do not include the dependencies on basic state variables of heat and moisture transport. In addition, the models always work with some parameters, which are not known explicitly (for instance hygric and thermal interface and surface resistances), and often neglect some effects (for instance Soret and Dufour effects), which can possibly be important under specific conditions. Therefore, the models have to be tested very thoroughly before they can be applied to serious service life prediction analyses based on modeling long-term hygrothermal performance.

At present, the mathematical models of heat and moisture transport are mostly tested using the measured data from selected test houses. This may not always be sufficient, particularly if some quite new hygrothermal problem is to be tested, which did not appear in exactly the same form in the previous test house measurements. In this respect, application of more flexible semi-scale testing systems can be considered as a reasonable solution for the improvement of the model validation and calibration procedure.

2 SEMI-SCALE EXPERIMENT

For the semi-scale experimental analysis, NONSTAT device developed recently in our laboratory was employed. The NONSTAT system makes it possible both to simulate climatic loading of investigated structure, which is of the same thickness as in the practical application on building site, and to measure thermal and hygric parameters. The NONSTAT system consists of climatic chamber system and of devices for monitoring moisture content, relative humidity, temperature and heat flux. All measuring and simulating processes are controlled by computer (see [1] for details).

2.1 Description of investigated building envelope

The tested building envelope consists from the exterior to the interior of a brick wall, water vapor retarder KAM on the cementitious basis developed by Sakret, capillary active mineral wool DU by Rockwool as thermal insulation and water vapor permeable plaster FFP also by Sakret (see Fig. 2)

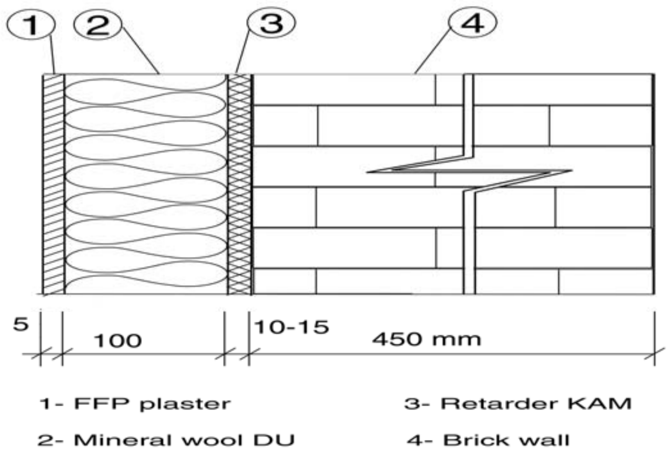

Fig. 1. Scheme of the tested structure.

The hygrothermal parameters of particular materials employed in measured building envelope were experimentally determined in our laboratory in order to obtain necessary data for computational analysis, (for details see [2], [3]). The summary of experimental results is shown in Table 1.

Table 1. Basic hygric and thermal properties of materials employed in investigated structure.

Sample		ρ [kg/m^3]	μ [-]	Ạ [kg/m^{2}s$^{1/2}$]	□ [m^2/s]	C (J/m^{3}K) E+06
DU	h	178	2.2	3.60E+00	1.51E-05	0.143
	s	96	2.2	1.33E+00	1.90E-06	0.097
FFP		1580	6.1	1.94E-01	1.76E-07	1,439
KAM		1321	11.9	1.77E-02	1.43E-09	1,342
Brick		1776	8.1	1.24E-01	1.52E-07	1,185

2.2 Measuring technology

In the investigated building envelope system, the sensors for measuring temperature, relative humidity and water content are installed into prepared bore holes and the upper part of the bore opening is water and vapor proof insulated by silicon sealing. The thermal flux sensors are spot glued on the front side of the measured envelope system. In the installation of the specimen into the connecting tunnel, its thermal and hygric insulation from the tunnel walls performed for the sake of simulation of one-dimensional heat and moisture transport in the envelope belongs to the main tasks. In our experiment, we employed extruded polystyrene boards in a combination with mineral wool, the front sides of insulation materials were covered by polyurethane foam.

The NONSTAT measuring system should simulate the hygrothermal processes in building envelope in conditions close to the reality. Therefore, the external and internal conditions simulated in the particular climatic chambers have to be realistic. We employ hourly reference-year based data for temperatures and relative humidities for Prague in the chamber simulating external climate and proper constant temperature and relative humidity data in the chamber simulating the internal conditions.

The measurement was first performed on non-insulated wall, and after 10 days there was applied the thermal insulation system. The climatic loading of the building envelope began with the climatic data for October 1. The measurement was done for the time period of 165 days and was finished with the climatic data for April 4. So, the whole winter period was simulated in the chambers.

3 COMPUTATIONAL ANALYSIS

The computational analysis of hygrothermal behavior of investigated building envelope was done using the computer code Delphin 4.3. It was developed by J. Grunewald at the Institute of Building Climatology of the Technical University of Dresden in order to support the investigation of the coupled heat, air, salt and moisture transport in porous building materials. Details on the code can be found in [4].

In the computer implementation of the analyzed hygrothermal performance problem, the computer generated mesh was adjusted to the real positions of the sensors in the measured envelope so that the same data could be obtained both in the experiment and in the calculations.

The climatic loading of the investigated structure during computational analysis was the same as in the semi-scale experiment. As climatic data were used data obtained from measurement in the particular climatic chambers. The hygrothermal parameters of particular materials employed in tested building envelope were taken from our laboratory measurements, for details see [2], [3].

4. RESULTS AND CONCLUSIONS

The measured results showed, that some overhygroscopic moisture appeared in the brick wall during the whole time of the experiment, and a part of it remained there until the end of the winter period (see Figs. 4-6 for the typical measured profiles on March 1). On the other hand, the capillary active mineral wool material DU remained dry during the whole critical part of the year, which is clearly a consequence of the high values of its moisture transport parameters. Therefore, taking into account all the negative and positive factors, the hygrothermal performance of the wall could be considered as relatively good in general.

The computational simulations performed with the data from Section 3 have shown a not very good coincidence with experimental data. Therefore, we have started a process of inverse modeling to achieve a better coincidence. As the main problems were in water content and relative humidity profiles, we tried to modify hygric parameters, namely the water vapor diffusion resistance factor and moisture diffusivity of the retarder and the moisture diffusivity of the brick. We have tested together 10 different combinations of the mentioned hygric parameters. The best results were achieved with the modified hygric parameters given in Table 2.

Table 2. Modified hygric parameters of used materials.

Material	quantity	original data	modified data
Sakret KAM	μ [-]	11.9	20.0
Sakret KAM	κ [m^2s^{-1}]	1.43e-09	1.43e-11
Ceramic brick	κ [m^2s^{-1}]	1.52e-07	2.00e-10

The comparison of experimental and calculated results where the modified hygric parameters from Table 2 were employed in the computational model is presented in Figs. 4-6. The differences in water content and relative humidity are relatively low, up to 5%, but the differences in temperatures are still relatively high, typically around 1-1.5^{0}C so that we can conclude that the overall agreement is not very bad but certainly a better agreement could be achieved with some other combination of parameters.

The relatively large differences between the original and modified data of hygric parameters that have led to better coincidence with the experiment deserve at least an attempt for explanation why something like that could occur.

First, better agreement with experimental data was obtained with the value of the water vapor resistance factor of the retarder two times higher than in the laboratory measurements. This is not very surprising because no interface water vapor transport resistances were taken into account in the model, so that we can assume that the higher value of μ in fact includes also these two resistances on both interfaces.

The significantly lower values of moisture diffusivity of the retarder and the brick (several orders of magnitude) obtained in the inverse modeling procedure are most probably a consequence of the fact that moisture diffusivities were assumed to be constant in the model. The dependence of moisture diffusivity on moisture content is mostly determined by an inverse analysis of measured moisture profiles and it is well known that κ can vary with the moisture content in the range of several orders of magnitude. We used the estimated average value calculated on the basis of a water sorption experiment (from this experiment only one value of water absorption coefficient is obtained, so we have only one value of moisture diffusivity). The reason for this choice were difficulties in determination of moisture profiles in mineral wool in the direction across the plate. In the inverse modeling we continued taking moisture diffusivity as a constant. In future computational experiments, it would be probably worth trying to include some dependence of κ on the moisture content although we do not exactly know the slope of the usually exponential curve.

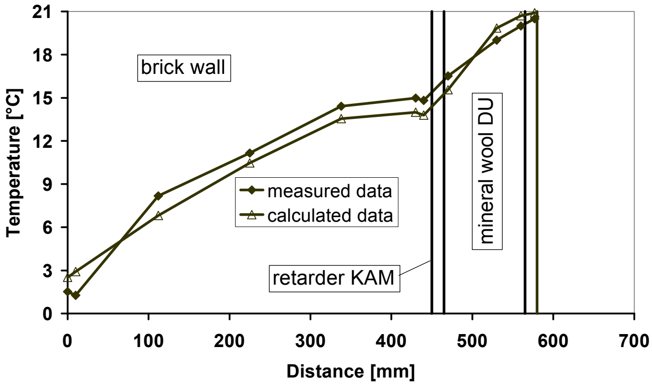

Fig. 2. Temperature profile in the tested structure for March 1.

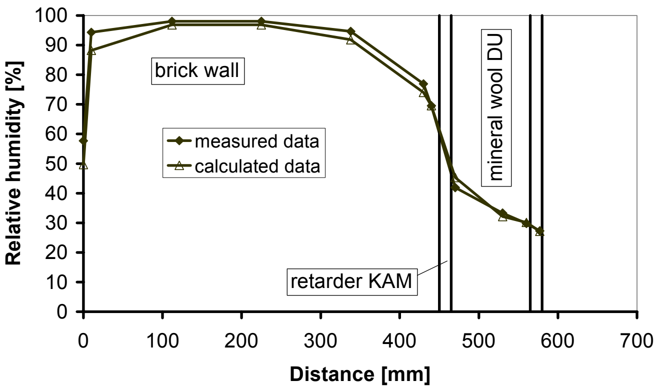

Fig. 3. Relative humidity profile in the tested structure for March 1.

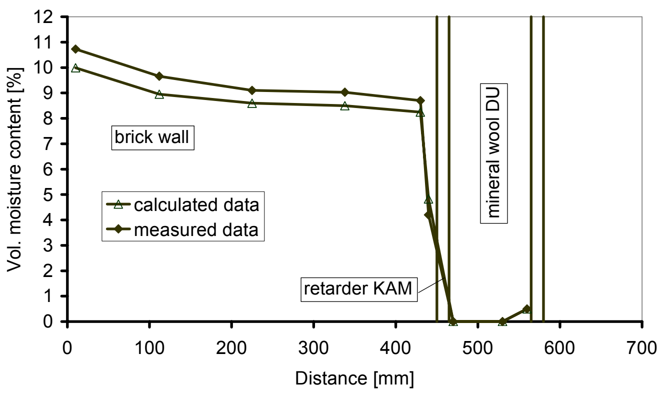

Fig. 4. Moisture content profile in the tested structure for March 1.

5. CONCLUSIONS

The comparison of experimental data from the semi-scale NONSTAT experiment with computational data obtained by Delphin computer code revealed the superior role of really complete determination of hygric and thermal properties used as input parameters of the model. This complete determination means primarily the dependence of all parameters on moisture and temperature in the whole ranges studied. The lack of these dependences for some of the parameters in this paper has led to difficulties in the process of inverse modeling because it was necessary to fit several parameters and too many combinations were available. From purely a mathematical point of view, fitting on more than one parameter is always problematic, so that the number of exactly unknown parameters should be lowered to an absolute minimum.

In future work, it is necessary first to return to the laboratory measurements of hygric and thermal parameters and to determine them completely as functions of temperature and moisture. It may be a very time consuming task because for instance measurements of sorption isotherms may take several months or more, and for some parameters, such as moisture diffusivity of plate materials as function of moisture content, the current measuring procedures have to be modified or maybe some new have to be developed. The second step then will be an inverse modeling with much better initial position, where it will be possible to concentrate on really unknown parameters such as interface resistances for moisture and heat transport.

Acknowledgement

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