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ELEMENTARY BENCHMARK OF COMSOL MULTIPHYSICS: ANALYTICAL MODEL VERIFICATION

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Abstract: *The main purpose of this article is in elementary benchmark test of program for numerical simulation called COMSOL Multiphysics. Essential goal is to validate presented simulation environment through analytically calculated thermal behavior of the wall. There is compared analytically calculated temperature distribution of transient heat conduction process with its numerical model results. Important settings of used simulation program for precise result are proposed.*
Key words: *transient heat transfer, benchmarking, numerical modeling, COMSOL Multiphysics*

1. INTRODUCTION

Buildings are complicated structures therefore a simulation of analogous geometries is complicated and it can lead to important model discrepancies. Internal building air temperature is influenced by variations of outdoor conditions such as temperature, solar radiation or overcast sky. Other important parameters for building simulation are wall overall heat transfer coefficient, internal heat gains or sinks caused by device such as lighting, occupancy etc., but also the window area.

The most important requirements for a simulation environment used in building simulation are: ability to predict stationary and transient heat transfer; compute three-dimensional model to simulate local effects in constructions e.g. in corners; furthermore, simulation results should be reproducible and accessible.

Significant tendency of decreasing energy consumption in building is evident in recent years and some simulation results of complicated systems were already presented in (Schijndel et al., 2008).

To evaluate accuracy of a numerical model (Judkoff & Neymark, 1995), recommended three types of tests:

- Analytical verifications;
- Comparison with other models;
- Validation with experimental results.

This article is focused on first part of COMSOL Multiphysics validation - analytical verification. An analytical verification of the whole building model is not able to realize due to its enormous complication. Nevertheless there were developed two test cases of one-layer wall for which analytical solutions are available.

Created thermal model of building segment will be benchmarked against analytical solutions of transient heat transfer equation in wall model.

The paper should provide necessary proof of COMSOL Multiphysics accuracy in heat transfer modeling, which is necessary for future program usage in complex model (Gerlich & Zalesak, 2010).

After successful numerical model validation by analytical problem solution it may be compared with another program utilize for heat transfer calculation as it is presented in (Tariku et al., 2010) – comparative benchmarking.

2. ANALYTICAL MODEL DESCRIPTION

Created numerical and derived analytical model are calculated from transient heat conduction equation which can be found in (Kolomazník et al., 1978) or (Hejzlar, 1999).

Temperature distribution in solid material is described generally in three-dimension, but for analytical model calculation it was simplified for one-dimension.

One-dimensional partial differential equation of transient heat conduction is

$$\frac{\partial \theta}{\partial t} = a \nabla^2 \theta , \tag{1}$$

where θ means temperature, t time and thermal diffusivity a is equal to

$$a = \frac{k}{\rho \cdot c_P} , \tag{2}$$

where k means heat conductivity, c_P heat capacity and ρ density.

The solution of this equation is based on the form of initial and boundary conditions (BC). There were used one type of initial condition – constant temperature in whole body – and two types of BC: fixed temperature on model surfaces (1^{st}-type BC); fixed heat flux on model surfaces (3^{rd}-type BC).

The wall model is constructed from a monolithic layer with following assumptions: initial temperature is at 60°*C*; ambient temperature held constant at 20°*C*; convective heat transfer coefficient held constant at 19 $W.m^{-2}.K^{-1}$.

Boundary condition of 1^{st}-type represents ideal heat transfer on phases interface, whereas the second case is more natural, because it calculates with finite value of heat transfer coefficient.

Temperature distribution of heat conduction for one-dimensional problem with 1^{st}-type BC is equal to

$$\theta^* = \frac{\theta(x,t) - \theta_a}{\theta_i - \theta_a} = 2\sum_{n=1}^{\infty} \frac{\sin(\lambda_n)}{\lambda_n} \cos(\lambda_n x) e^{-\lambda_n^2 F_0} , \tag{3}$$

where θ^*, θ_a, θ_i mean dimensionless, ambient and initial temperature, respectively and λ_n is equal to odd multiple of π

$$\lambda_n = (2n-1)\frac{\pi}{2} \tag{4}$$

and Fo is Fourier number

$$Fo = \frac{a \cdot t}{d^2} . \tag{5}$$

The second case of temperature distribution (with 3^{rd}-type BC) is described by equation

$$\theta^* = \frac{\theta(x,t) - \theta_a}{\theta_i - \theta_a} = 2\sum_{n=1}^{\infty} \frac{\sin(\lambda_n)}{\lambda_n + \sin(\lambda_n)\cos(\lambda_n)} \cos(\lambda_n x) e^{-\lambda_n^2 F_0} , \tag{6}$$

where λ_n are roots of transcendental equation

$$ctg\lambda = \frac{\lambda}{Bi} , \tag{7}$$

where Bi is Biot number

$$Bi = \frac{h \cdot d}{k}\,, \quad (8)$$

where h means convective heat transfer coefficient and d characteristic length.

3. NUMERICAL MODEL DESCRIPTION

Domain and boundary parameters were set according to previous chapter to rectangular wall geometry.

It is concluded from numerical simulation results that it is not possible to use default program settings to get precise simulation results – there is important to set at least 10-times smaller relative and absolute errors in solver settings; and also it is necessary to create mesh with very fine elements. Hence swept mapped mesh was used with 20 layers.

Simulation results with default solver and mesh settings appeared in consonance with analytical solutions, however the unsuitable model settings caused constant difference between the solutions in entire wall width.

4. MODEL VERIFICATION

Numerical model validation by analytical solution based on the equations presented in previous chapters is discussed now. The above equations describing temperature distributions were solved with 8 roots of parameter λ_n hence theirs calculation were very precise.

The comparison of numerical and analytical models is presented in Fig. 1 and 2. Analytical results are showed by solid line and outputs from numerical models are showed by dashed line. There are compared temperature distribution in 5 different moments – 30 *s*, 60 *s*, 2 *min*, 5 *min*, 15 *min* and 5 *min*, 10 *min*, 30 *min*, 1 *hour* and 4 *hour*, respectively. Temperature distributions from created models in dimensionless wall profile are very close. The figures showed temperature profile only from half of the wall considering the model symmetry.

It is obvious that temperature model course with 1st-type BC is lower than in second case. This is caused by infinite value of heat transfer coefficient which can be derived from the relation between BC of 1st and 3rd-type.

5. CONCLUSION

There were verified several important facts about the usage of COMSOL Multiphysics for building simulation:

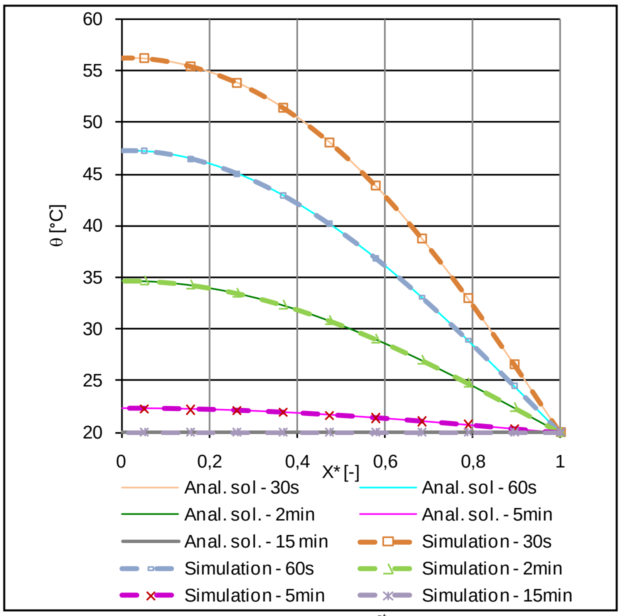

Fig. 1. Temperature distribution with 1st-type BC

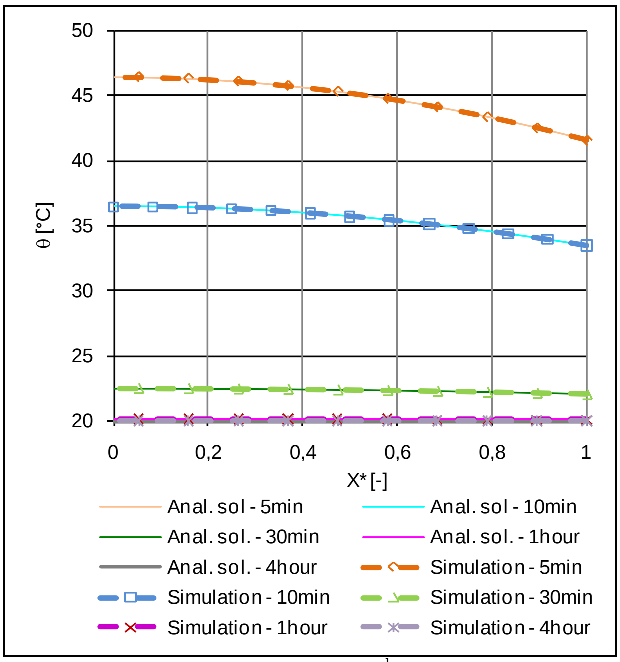

Fig. 2. Temperature distribution with 3rd-type BC

- It is necessary to set numerical solver error to at least 10-times smaller values in comparison to default values.
- The model has to be calculated with very fine mesh to decrease numerical model error.

It can be concluded that numerical prediction of COMSOL Multiphysics is in excellent agreement with the analytical solution only if the numerical solver is set properly.

The work for further research will be in presented program validation by comparative test e.g. BESTEST methodology and also in creation room model with validation by measured data.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Gerlich, V. & Zalesak, M. (2010). Experimental Validation of Heat Transfer Model (2010). 0969-0971, *Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium*, ISBN 978-3-901509-73-5, ISSN 1726-9679, , B. Katalinic (Ed.), pp. 0969-0970, Published by DAAAM International, Vienna

Hejzlar, R. (1999), *Sdílení tepla*. ČVUT, ISBN 80-01-01982-9, Praha

Judkoff, R. & Neymark, J. (1995), Building Energy Simulation Test (BESTEST) and Diagnostic Method, *CO National Renewable Energy Lab*,. NREL/TP-472-6231

Kolomazník, K.; Sedlář, J. & Macháčková, A. (1978), *Teorie technologických procesů III*, Rektorát Vysokého učení technického v Brně, ISBN 55-588-78, Brno

Schijndel, A. W. M van; Schellen, H. L.; Wijffelaars, J. L. & Zundert, K. van. (2008). Application of an integrated indoor climate, HVAC and showcase. *Energy and Buildings*.No. 40, 647–653. ISSN 0378-7788

Tariku, F; Kumaran, K. & Fazio, P. (2010). Integrated analysis of whole building heat, air and moisture transfer. *International Journal of Heat and Mass Transfer*, Vol. 53, No. 15-16, (July 2010) 3111–3120, ISSN 0017-9310