Modelling and Experimental Validation Possibilities of Heat Transfer Room Model

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Abstract: The study presents first authors experience with COMSOL Multiphysics environment used as a possible modelling tool of thermal building behaviour. There are known many application of the COMSOL for 1D and 2D problems, but 3D problem description was not found frequently in literature in the field.
The idea of the project was to gain thermal response to changed boundary conditions with the application of COMSOL environment as a modelling tool for 3D buildings or 3D building segments. The room as building segment was implemented in the COMSOL environment. Physical parameters and boundary conditions were set to the individual structures.
The first experience with the COMSOL application in the field, details of the thermal experiment and first results of the evaluation are described in the submitted article.

Keywords: heat transfer, thermal modelling, building simulation, numerical modelling, COMSOL Multiphysics

1. Introduction

Energy consumption in buildings in EU is approximately 40% of the total consumption. Due to an effort to decrease energy consumption, the attention is paid to the energy consumption on building sector and related energy saving measures, as well. The obvious measure is to increase thermal insulation properties of buildings envelopes, however nowadays buildings are reaching the economically proved limit. The one of possible way to farther decrease energy consumption for heating/cooling of buildings is to optimize the energy supply strictly per time schedule. This concept requires the necessity to consider of thermal accumulative properties of buildings as well.

In general, buildings and its structures create from the point of view of heat transfer a complicated and complex object. An analytical solution of such a complicated object with focus into consideration of thermal unsteady (transient) state and various boundaries conditions is nearly obsolete. The technical possible solution of the above stated tasks could be provided only on the substantial simplifications. These simplification methods were widely published in literature and finally stated in technical standards e.g. [1] or [2], nevertheless they do not give reliable technical outputs, which could not be taken for practical usage. Accessible computing power at present enables to solve the complex task by simulation methods, which reflect more accurate the reality. On the other hand, it is not possible to model some specific details like thermal bridges, specific conditions in corners etc. by the reason of usage finite element analysis which has problems or even crashes with meshing similar details.

The increasing computer power enables to use energy analysis software for buildings simulation on personal computers. There is a list with more than 200 building-energy software tools on the web pages of U.S. department of energy. Such tools utilize a number of different approaches for calculating building energy consumption. Very important parameter of these software is their accuracy due to theirs utilization in the field of energy savings and thermal comfort of inner environments with premises optimization.

2. Thermal behaviour of the modelled room

Heat transfer phenomenon is described by Partial Differential Equations (PDEs). The solution enables building description from the view of heat behaviour.

2.1 Domain settings

The heat transfer in presented model is characterized by conduction in the wall and convection in internal air. Equation which describes this problem is

$$\rho \cdot c_P \cdot \frac{\partial T}{\partial t} + \nabla(-k \cdot \nabla T) = Q, \qquad (1)$$

where ρ means density, c_P heat capacity, T room temperature, t time, k heat conductivity and Q heat source.

2.2 Boundary settings

The second important equation describes boundary conditions of the modelled room. Continuity boundary conditions were set on the inner model boundaries and there are set the heat flux values on the outer sides of the walls. The heat fluxes are computed from equation

$$q = h \cdot \left(T_{\text{inf}} - T\right), \qquad (2)$$

where q means heat flux, h heat transfer coefficient, T_{inf} outer temperature and T room temperature.

3. Model creation

Indoor airflow and local constructions models based on PDEs can be implemented in many software e.g. ESP-r [3] or COMSOL Multiphysics [4], but most of these models are created as 1 or 2 dimensional [5, 6].

The three-dimensional model of the laboratory room was drawn in Autodesk Inventor and imported into COMSOL. Individual parts of the room model (subdomain) are showed in Figure 1.

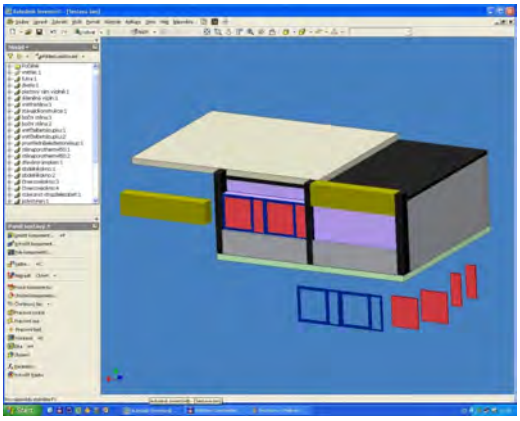

Figure 1. Autodesk Inventor model of the laboratory room.

Thermal parameters of the walls and internal air were set by the material table parameters which are showed in the appendix. The detail structure of the modelled room can be seen in the blue print which is showed in Figure 2.

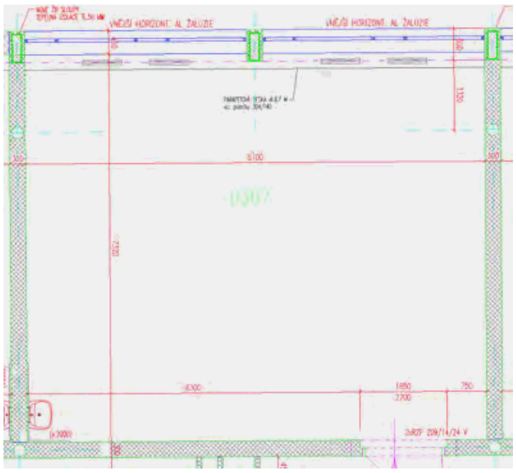

Figure 2. Blue print of the modelled room.

The model was not created in current COMSOL version but in FEMLAB version 3.1. There were problems with modelling time dependant variables, especially with time-varying boundary conditions which caused that it was necessary to do many several-hours simulations in loop to get several days' temperature development. The similar problem is also modelled in current COMSOL version nowadays, without the earlier problems. Notwithstanding, the model is not fully finished yet, but the preliminary temperature outputs are much closer to the real temperature course than output data from the model created in FEMLAB.

There was created free mesh consists of about 43 000 degree of freedom to calculated presented model. Simulation was done in time-dependent iterative solver based on conjugate gradients. Simulation of ten hour took on computer with 1.7 GHz processor and 1 GB RAM about 90 seconds, model was simulated with 1800 seconds time steps.

5. Model results

The comparison of the FEMLAB (COMSOL) outputs with experimentally measured data is discussed now. The main simulation goal was to get sufficient agreement with the measurement. The model will be considered as accurate enough, if the difference between simulated and measured values will not be larger than ± 0.5 degC.

At first, temperature distribution in the model was studied. As was expected; the coldest parts of the room are on external wall, and especially in the space where is steel-reinforced concrete as could be seen in Figure 3. Because of lower thermal resistance are these parts so-called thermal bridges.

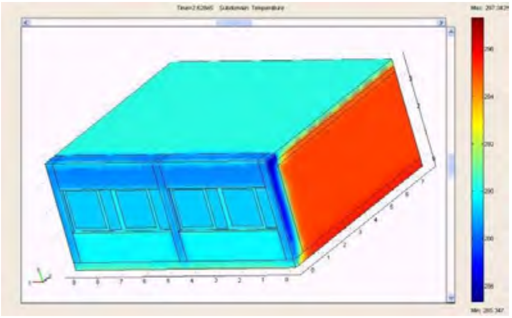

Figure 3. Room temperature distribution.

The second simulations focus on a free-room cooling. The room temperature was set to the initial value and external boundaries conditions were set to the measured temperature values. These temperature data was measured in ambient rooms and external air. Three-dimensional temperature profiles and heat fluxes (cones) of free-cooling room are shown Figures 4-7.

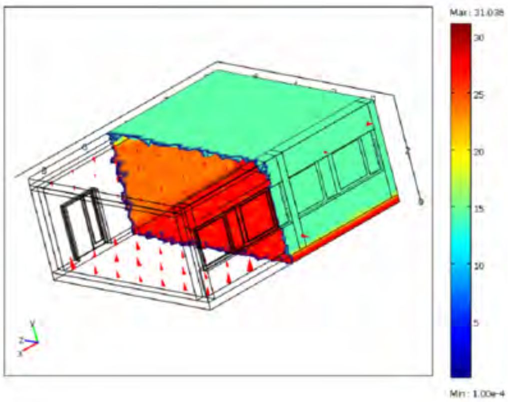

Figure 4. Room temperature on the beginning of the simulation.

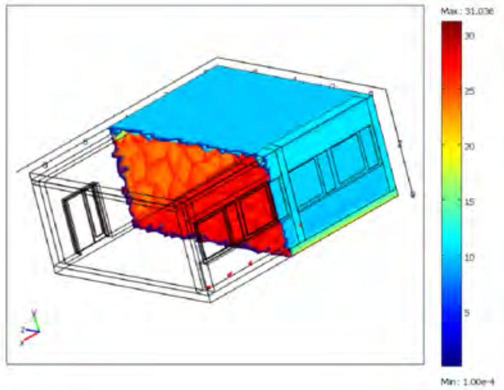

Figure 5. Room temperature after 3.5 hours.

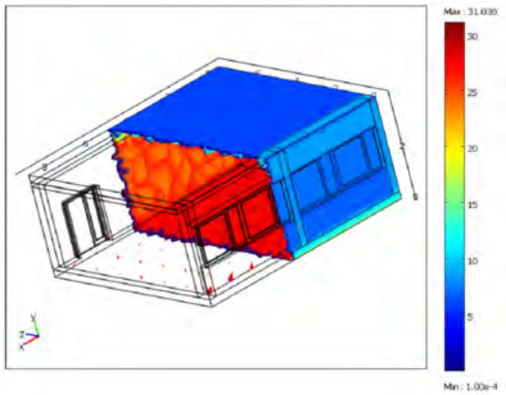

Figure 6. Room temperature after 7 hours.

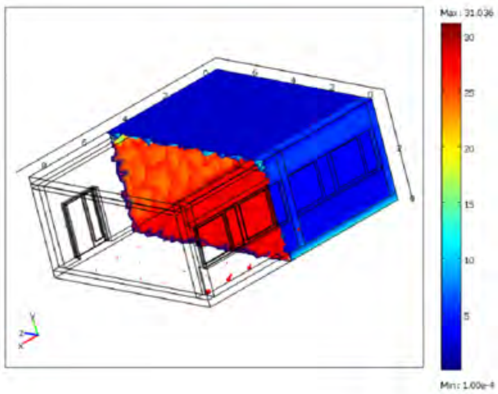

Figure 7. Room temperature after 10 hours.

Temperature time-development of the room is shown in Figure 8. The graph represents simulated internal air temperature response in the position, where the globe thermometer was placed (6 meters from the door, 2 meters from the external wall and 1.3 meters above floor). The importance of this response is in its usage for coefficients of the transfer function calculation. This transfer function can be used for further room modelling in MATLAB environment.

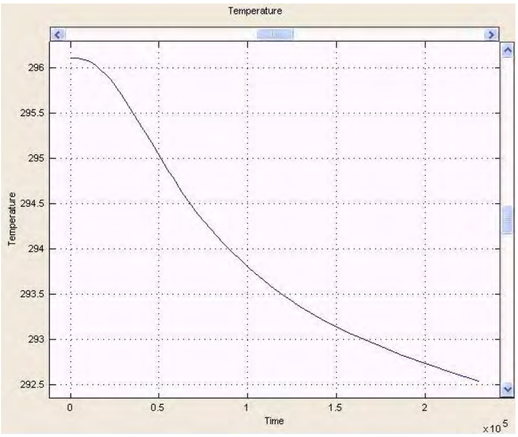

Figure 8. Room temperature after 10 hours.

The third simulations focus on the room temperature step response. There were set additional internal heat source which was added into subdomain setting of the internal air.

In spite of the fact, that COMSOL is able to solve PDEs equations with good agreement with analytical solution [5], it is obvious, that COMSOL outputs are not similar to measured data as it would be sufficient. As can be seen in Figure 9, time behaviour has the same trend as measured data, but there is large maximal temperature difference 1.35 degC and mean temperature difference 0.662 degC between these series. Because of this important temperature differences it is not fulfilled necessary accuracy. It is evident that these data are relatively smooth, so it is probably some problem with time constants of the system or other model properties.

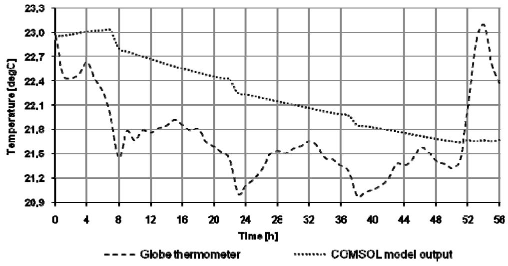

Figure 9. Simulated and measured temperature course.

6. Conclusions

This study is a contribution to the numerical solutions of thermal analyses in buildings as regards as the performance of FEMLAB/COMSOL Multiphysics program in this field. This software tool was chosen due its ability to good cooperation with several CAD programmes and due to modelling complexity.

It was created real room model and consequently temperature behaviour was simulated. It was investigated temperature-time dependency on variable boundary conditions of the modelled room.

The accuracy of the model was compared to the measured temperature course of an internal room air. It is noticeable; because of previous successful COMSOL environment application in similar problems that created model has to contain some internal mistake. It is necessary to find and fix the mistake(s) or even draw new model geometry during the future work because model did not fulfil the desired accuracy.

The model of the room is updated to the current COMSOL version and new experimental validation of the model will follow. After the validation is proved, the simulation of thermal behaviour of complex structures could be designed, which could finally leads to energy optimization process in the energy consuming sectors.

Another model improvement can be in its cooperation with MATLAB or other software tool for feedback control. COMSOL environment has a great advantage in this area, because it had been developed as the MATLAB toolbox.

7. References

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9. Appendix

Table 1: Material parameters

Material	$k\left[W.m^{-1}.K^{-1}\right]$	d [mm]
Porotherm 300	0.25	300
Porotherm 400	0.15	400
Polystyrene – external wall	0.034	50
Polystyrene – ceil	0.034	280
Concrete	1.43	180

Table 2: Nomenclature

T	Room temperature [K]
$T_{\inf}$	Outer temperature [K]
Q	Heat source [W]
q	Heat flux [$W.\ m^{-2}$]
h	Heat transfer coefficient [$W.m^{-2}.K^{-1}$]
k	Thermal conductivity [$W.m^{-1}.K^{-1}$]
ρ	Density [$kg.m^{-3}$]
t	Time [s]
c_P	Heat capacity [$J.kg^{-1}.K^{-1}$]
d	Thickness [mm]