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EXPERIMENTAL VALIDATION OF HEAT TRANSFER MODEL

GERLICH, V[ladimir] & ZALESAK, M[artin]*

Abstract: *A reduction of energy consumption in buildings is complex task therefore an integral approach for model creation is required. In order to predict environment temperature precisely a model of one room has been developed. A heat transferred based model is used for description of correlation between temperature in the modelled room and surrounding areas. A finite element model was developed in 3D coordinates in order to achieve illustration of an air and an energy movement and to simulate the transient process in the walls. The study presents that the simulation environment can be a useful tool for solving heat transferred.*
Key words: *heat, modelling, buildings, COMSOL multiphysics*

1. INTRODUCTION

Building constructions are structures with many bindings and their inside temperature distribution is influenced by the variance of outside heat conditions, wall parameters and internal heat gains or sinks caused by an occupancy or an air-conditioning system. Analytical solution of transient (non-stationary) heat transfer is complicated and mostly solved only with significant simplifications so it is appropriate to use computing power for simulation such complex task. Specialized computer software is based on a numerical solving heat transfer phenomenon which is described by Partial Differential Equations (PDEs). The solution enables building description from the view of heat behaviour and it also provides the possibility to design optimal system for heating/cooling. Combination of a software tool for building simulation with an appropriate tool for close-loop simulation allows designing suitable controller for specific building conditions (Schijndel, 2008).

Building-energy software tools are used for the simulations of heat transfer processes of inner environment properties in buildings in combination with heating and ventilation systems (HVAC). COMSOL Multiphysics (formerly FEMLAB) had already been experimentally verified for building simulation (Schijndel, 2008, Šišák, 2006).

Necessary part of any model development is its validation and testing in order to ensure its credibility by an eliminating algorithmic shortcomings and physical simplifications as concern as boundary conditions and others. This study is based on the model development and its comparison to measurement.

2. REQUIREMENTS FOR SIMULATION TOOL

The important requirements for a simulation environment are discussed now. First goal is to predict dynamic heat transfer process in buildings therefore, it is essential requirement that the simulation environment incorporates a suitable model that is able to predict temperature responses of indoor climate of whole building with the required timescale and accuracy. The second goal is to include 3D model to simulate a local effects in constructions and an indoor climate. Furthermore, modelling and simulation results should be reproducible and accessible.

A model creation contributes to determination of the thermal dynamical parameters of different systems. The structure of geometry based models is often based on PDEs and building simulation can be implemented in many software packages e.g. ESP-r, TRNSYS or COMSOL Multiphysics. There is compared measured temperature course with the output data from COMSOL Multiphysics in this paper.

2.1 COMSOL Multiphysics

COMSOL Multiphysics is a tool for modelling scientific and engineering applications based on PDEs. It offers a multiphysics modelling environment, which can simultaneously solve multiple physics equations. Important features are e.g. direct and iterative solvers, stationary, parametric and a time dependent analysis, ability to solve linear or non-linear problems, modelling in 1D, 2D or 3D (COMSOL, 2010).

3. THERMAL BEHAVIOUR OF THE MODELLED ROOM

There was measured a room air temperature during the experiment and the data was compared to the simulation outputs. The goal of the experiment is to create a model which will be able simulate the real building energy flows.

The modelling procedure in COMSOL program consists of three phases – pre-processing (geometry creation, domain and boundary parameter settings), processing (mesh creation, model calculation) and post-processing (data presentation and evaluation). The possibility of physical phenomenon modelling without needs of punctual mathematical equations is a great advantage of this software. On the contrary, complicated models are hardly created in COMSOL environment and they have to be imported from CAD programs such as CATIA V4 or V5, Pro/ENGINEER, Autodesk Inventor, etc., due to CAD Import module.

The three-dimensional model of the laboratory room was drawn in Autodesk Inventor according to the room blue print and imported into COMSOL Multiphysics environment as you can see in Fig. 1.

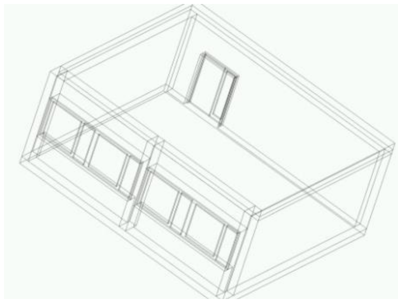


Fig. 1. a) Room model

3.1 Domain settings and boundary conditions

The heat transfer is expressed by conduction and convection and the major balance equation which describes this problem is

$$\rho \cdot c_p \cdot \frac{\partial T}{\partial t} + \nabla(-\mathrm{k} \cdot \nabla T) = \mathrm{Q} \quad (1)$$

where ρ means density, c_p heat capacity, T room temperature, t time, k heat conductivity, Q heat source. Each part of the room is a subdomain and these subdomains are solved in parallel.

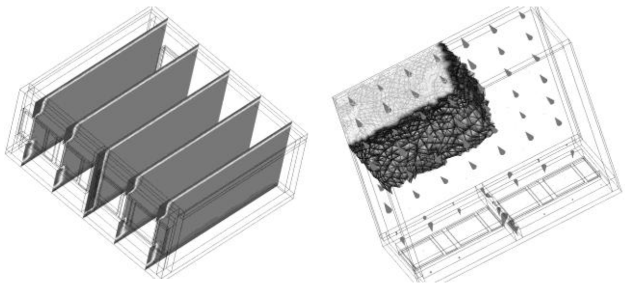
The major equation has to be solved with specific boundary conditions, which are important for output temperature calculations. Continuity boundary conditions were set on the inner model boundaries and the heat flux boundary conditions were set on the outer sides of the walls. The heat flux is computed by general convection equation, the convective heat flux is given by following equation

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

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

Eq. (2) is calculated with two values of heat transfer coefficient. The external walls have the heat transfer coefficient equal to 23 $W.m^{-2}.K^{-1}$ and it is calculated with value 8 $W.m^{-2}.K^{-1}$ on the indoor walls. Generally, it is considered natural convection on indoor walls so the fluid motion is caused only by buoyancy forces. The values of heat transfer coefficient are specified by CSN standard. Information about heat transfer coefficient in boundary layer can be found in (Zálešák & Kašpar, 1982).

It is not possible to set plant simulation or fluid flow in COMSOL environment like in the software specialized in heat transfer problematic e.g. ESP-r. On the other hand, the model output presentations are much more illustrative as is shown in Fig. 2.



a) b)

Fig. 2. a) Temperature distribution in the room b) Temperature subdomain plot with heat flux (cone)

Created room model contains 30 subdomains with 192 boundaries. The problem calculation used Finite Element Method (FEM), the model consists of 29 938 degree of freedom (DOF), total number of tetrahedral mesh elements is 20 237 with the minimal mesh quality 0.0253. The mesh quality is computed internally

$$MQ = \frac{72\sqrt[3]{3} \cdot V}{(h_1^2+h_2^2+h_3^2+h_4^2+h_5^2+h_6^2)^{3/2}} \quad (3)$$

where V means volume, h_i edge lengths.

4. THE COMPARISON OF SIMULATED AND MEASURED DATA

The comparison of the simulation output and the measured data are discussed now. The model will be considered as accurate enough, if the difference between simulated and measured values will not be larger than ± 0.5 K.

Because of the high growth of the room temperature after the 50^{th} hour, only data till this time will be evaluated.

In spite of the fact, that COMSOL Multiphysics is able to solve PDEs equations with good agreement with analytical solution (Zimmerman, 2006, Schijndel, 2008), it is clearly seen in Fig. 3 that simulation output is not accurate enough. The time behaviour has the same trend as measured data, but there is maximal temperature difference 1.35 K and mean temperature difference 0.662 K. The difference between simulated and measured data may be due to a problem with system time constants or inside model property.

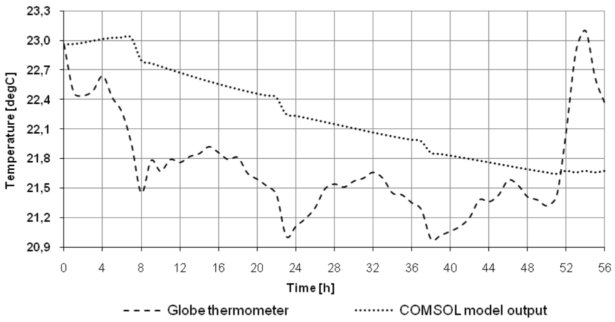


Fig. 3. Comparison measured and simulated data

5. CONCLUSION

There was presented room model based on heat transfer process. The model was created in COMSOL Multiphysics, which is a new software package for physical simulations.

The accuracy of the model was compared to the measured temperature course of an air in the room. It is noticeable, because of previous succesfull 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.

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

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