INFLUENCE OF RADIATIVE HEAT TRANSFER TO ROOM TEMPERATURE

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The work behind the article was supported by the European Regional Development Fund under the Project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089 and by the by the internal grant agency of Tomas Bata University in Zlin with NO. IGA/44/FAI/10/D.

Abstract: The main idea of the room model development is to simulate thermal response of the building construction into changing boundary conditions. The room model was created and subsequently the thermal analysis was calculated. The central idea of this article is to study radiation influence to overall room temperature. Heat transfer by radiation can lead to two problems during simulation. Firstly, this phenomenon is strongly non-linear and secondly, precise emissivity value is uncertain. There is discussed an error due to neglecting radiation process for internal building conditions and also the possibility to model radiation by means of raising the value of heat transfer coefficient by convection. Temperature course of the simplified model is analyzed and compared to the original model output.

Keywords: heat transfer, radiation, building simulation, COMSOL Multiphysics.

Tab. 1: Nomenclature

Nomenclature			
T	Room temperature [K]	k	Thermal conductivity [$W.m^{-1}.K^{-1}$]
T_{inf}	Outer temperature [K]	c_P	Heat capacity [$J.kg^{-1}.K^{-1}$]
T_{amb}	Ambient temperature [K]	t	Time [s]
h	Convective heat transfer coefficient [$W.m^{-2}.K^{-1}$]	ε	Emissivity [-]
v	Speed [$m.s^{-1}$]	σ	Stefan-Boltzmann constant [$kg.s^{-3}.K^{-4}$]
Q	Heat source [W]	ρ	Density [$kg.m^{-3}$]
q	Heat flux [$W.\ m^{-2}$]		

1 Introduction

Building constructions are structures with complicated bindings; internal temperature value is influenced by variation of outside conditions (external temperature, humidity, solar radiation etc.) as well as by temperature in ambient areas or by internal heat gains or sinks caused by device or occupancy. Important parameter of building construction is overall heat transfer coefficient, which determines the wall heat resistance.

Transient (non-stationary) heat transfer is formulated by second order Partial Differential Equation (PDE) therefore it is necessary to solve time and x, y, z derivation for calculating 3-dimensional temperature room distribution. Analytical solution of transient heat transfer is possible to count only for simple geometries thus complicated structures are solved only with significant simplifications. Therefore complex problems have to be solved numerically. Taking into account the facts mention before physical problems based on PDE are in these days calculated by the usage of computer power. A number of computer software mostly based on finite volume or finite element method can be used for numerical solution of Heat Transfer (HT) phenomenon. It is even possible to simulate these problems on personal computers (nowadays common 64-bit dual-core processors with several gigabytes of RAM) because of the increasing computer power.

Simple problems such as wall stationary temperature distribution or transient phenomenon in simple objects can be solved as 2-dimensional or even 1-dimensional tasks; contrariwise more complex problems have to be solved as 3-dimensional models. These complex models naturally need more computing power, memory and time because of the huge number of elements in which the dependent variables have to be calculated. Problem complexity can be even larger, if it is important to couple more physics into one model such as heat and mass transfer. The number of elements can be reduced, if the specific problem is solved as symmetrical problem, but evidently this presumption is hardly fulfilled in strongly complex models.

The program used in this article for numerical calculating transient HT in buildings is COMSOL Multiphysics (formerly FEMLAB). The main program ability is based on numerical solving of PDE by finite element method. The software tool is used for HT calculation in this work however its usage is much wider as it can be seen in [1]. Nevertheless it was not used for building simulation too often. The usage of this program for similar problems can be found in [2, 3]. Program advantage is its ability to cooperate with MATLAB environment, which will be important for future control strategy development, examples of this linking are in [4].

In contrast to the paper [5], which was focused on model simplification due to HT by conduction from ambient rooms, is centre of this work HT by radiation. Heat transfer by radiation can caused simulation problems because of two main process characteristics. Firstly, this phenomenon is strongly non-linear and so it can bring instability of numerical solution. Secondly, precise emissivity value is uncertain, because it is variable with temperature and surface conditioning.

1.1 Experiment description

Used data were measured during the experiment since December 2010 till January 2011 in Zlin, Czech Republic. Experiment room area was (7.2x8.7x3) *m* and time period was nearly 19 days. Temperature was measured by globe and NiCr thermometers in modeled room area. External weather conditions were monitored by meteorological station placed on the roof at Faculty of Applied Informatics. The room was cyclically heated up and cooled down. Convector electric heaters were used as heat sources to control raising heat power precisely. There were used 2 electric heaters with heat power 2 and 3 *kW* respectically. Room temperature fluctuated during experiment period in range from 14 to 30*°C*.

The room is located on the top floor and it has one wall and roof influenced by external weather conditions. The rest of the room walls are affected by temperatures in internal areas which have their heat conditions very similar to the room temperature.

2 Mathematical model description

Heat transfer in modeled room is described by conduction and convection in walls and by conduction, convection and radiation in internal air. Fundamental equations which describe HT are presented in following chapters; more detail information about HT can be found in e.g. [6].

2.1 Domain settings

While conduction describes the heat passage through the wall and partially the HT in internal air, convection describes the HT in internal room air. Thus the major balance equation in domains is composed from 4 parts, where the first refers to HT by conduction, the second to convection process and the third part to heat accumulation in the mass of specific domain. The sum of these three processes is equal to domain heat source as you can see in following equation

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

where k means heat conductivity, T room temperature, ρ density, c_p heat capacity, v speed, t time, Q heat source.

2.2 Boundary settings

There are used three types of boundary conditions. Firstly, Neumann boundary condition was calculated on external boundaries and boundaries related to internal air

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

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

The values of Convective Heat Transfer Coefficient (CHTC) were set by CSN standard [7]. The value on the outer side of external walls was equal to 8 $W.m^{-2}.K^{-1}$ and it had value 2.5 $W.m^{-2}.K^{-1}$ on internal building walls, since it was calculated only with convection process.

On boundaries with internal air was active also second boundary equation, which describes HT by radiation

$$q = \varepsilon \cdot \sigma \cdot \left(T_{amb}^4 - T^4\right), \qquad (3)$$

where ε means emissivity, σ Stefan- Boltzmann constant, T_{amb} ambient temperature, T boundary temperature.

Thirdly, it was used continuity boundary condition on the rest of boundaries e.g. internal boundaries between different wall domains.

3 Simulation

The model geometry was drawn in 3D construction design software CATIA and imported to the COMSOL Multiphysics environment. Equations for HT in solid domains were set by (1), however without the second equation term, in liquid domain (internal air) were used (1), on outer boundaries were used (2) and on inner boundaries were used (2) and (3).

3.1 Simulation properties

There was used free mesh with about 32 000 Degrees Of Freedom (DOF) and average simulation time on this machine was about 1200 s. Additionally, it was also studied coarser and finer meshes. There was a problem with creating coarser mesh than 16 000 DOF, because mesh creation crashed on narrow's regions, vice versa finer meshes had no problem with problem calculation, but it was not necessary use finer mesh by reason of minimal result differences. Clearly, demandingness of computing power increase significantly with complexity; hence we do not wish unnecessarily large number of DOF.

There was tested 2 solver tolerance. The first setting was with relative and absolute local error tolerance in the PDE solver of 10-3 and 10-4 respectively and the second solver setting was with even 10x smaller errors. The simulation results were almost identical, however simulation time were more than 3x longer with second setting. We use linear PARDISO solver, since it is supposed to profit most from the multithreading solver capability.

The model was calculated in COMSOL Multiphysics v3.5a on computer with 2 processor - Intel Xeon (2.33 GHz, 2x6 MB cache L2, quad-core) - with 4 GB RAM.

3.2 Simplified model verification

There is investigated overall radiation effect on room temperature for different HT setting. Heat transfer by radiation is ordinary described by eq. (3), but it is also possible to model this phenomenon due to enlarged value of CHTC – ordinary by 5.5 $W.m^{-2}.K^{-1}$.

Three variants of room model are compared with measured temperature course by wet bulb globe thermometer in Fig. 1. Simulation results of updated model suffer from decreased HT by radiation which leads to higher temperature differences in experiment parts when room is heated up. Simulation outputs of newly proposed models are slightly more accurate in cooling phases but this difference is not as significant as its negative behaviour in heating phases.

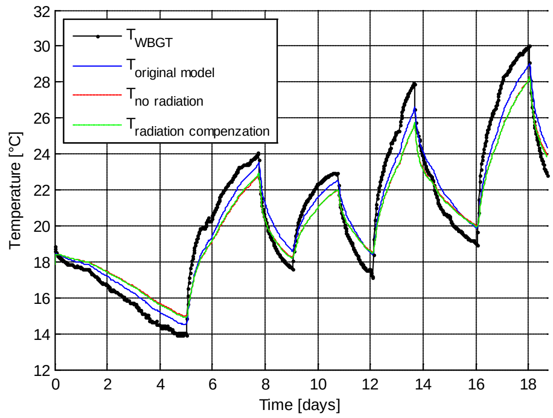
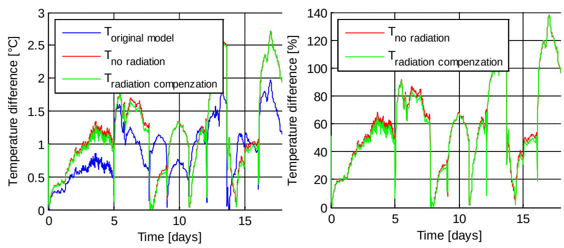


Fig. 1: Room temperature development

Time-developments of absolute and relative temperature differences are showed in Fig. 2. Absolute model differences fluctuate up to 2.72°C. Simplification of radiation process leads to increasing temperature error which is manifest in Fig. 2 a) where time-course of updated model errors is for the majority of the simulation time above original model error. The relative temperature errors of simplified models are compared with original model in Fig. 2 b). The most important facts resulting from this figure are consequently described in the table.



a) b)

Fig. 2: Room temperature development

There are compared 3 variants of created model in Table 2. Firstly, there is original model which is based on HT by radiation by Eq. (3) and convection phenomenon with CHTC value equal to 2.5 $W.m^{-2}.K^{-1}$. Secondly, there is simplified model which neglect radiation process. Third model is also without radiation process, but in this case radiation is compensated by higher CHTC value. The CHTC parameter is in this model equal to 8 $W.m^{-2}.K^{-1}$.

There is calculated relative mean error of newly proposed models in comparison to original model. It is obvious that these simplifications lead to about 20% higher model error and only to minimal time savings about 5%.

Tab. 2: Comparison of different modelling methods of HT by radiation

Model types	*Relative error [%]*	*Simulation time [s]*
Original model	100	1180
Without radiation	123	1120
Higher value of CHTC	120	1122

Truncation of HT by radiation caused significant model error as well as its modelling by higher value of CHTC. Generally, it is evident that proposed simplified models do not save simulation time.

4 Conclusion

There were proposed two variants of present-day model based on HT process to prevent numerical calculated errors as well as to save simulation time.

Simulation outputs indicate that the usage of similar simplifications lead to increasing modelling error about 20% and minimal decreasing of simulation time.
Simplified model presented in [7] was able to save significant measurement of resources in contrast to current simplifications. There is clearly seen from simulation results that current model should not be simplified in the sense of HT by radiation.

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Primary Paper Section: B

Secondary Paper Section: BJ