Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 14 (2012) 744 – 749

Energy Procedia

2011 2nd International Conference on Advances in Energy Engineering

Benchmark of COMSOL Multiphysics via in-depth floor slab test – Transient cases

Gerlich Vladimir[a], Oplustil Michal[a], Pisan Radim[a], Zalesak Martin[a]a*

[a]*Tomas Bata University in Zlin, Faculty of Applied Informatics, nám. T.G.Masaryka 5555, Zlín, 760 01, Czech republic*

Abstract

The main purpose of this article is an advanced thermal benchmark of COMSOL Multiphysics simulation tool. The program is validated by analytical and comparative verification tests provided by the International Energy Agency in Task 34 called "In-Depth Diagnostic Cases for Ground Coupled Heart Transfer Related to Slab-on-Grade Construction". Building energy simulation test cases for evaluating simulation software are created, simulated and evaluated in software COMSOL Multiphysics. Essential goal of this article is evaluating of new simulation environment for building simulations. There are compared numerically calculated thermal flow results of transient heat conduction as well as boundary convection process in COMSOL Multiphysics with analytical and numerical model outputs presented in Task 34.

Keywords: heat transfer; benchmark; COMSOL Multiphysics; BESTEST; slab-on-grade

1. Introduction

Buildings are complicated structures with many bindings because of complicated geometry and variable boundary conditions. Internal air temperature is influenced by variations of outdoor conditions such as temperature, solar radiation or overcast sky. This temperature value directly influenced overall building heat loses, videlicet the price which has to be annually paid for building usage. It is necessary to use universal software tools for simulations of heat building behavior to be able to propose optimal wall parameters.

Energy consumption in buildings generates about 40% of energy supply in European Union in recent years, but reduction of energy consumption via additional decrease of the wall U-value in the following

* Corresponding author. Tel.: +420-734-681-112.
E-mail address: gerlich@fai.utb.cz.

1876-6102 © 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of the organizing committee of 2nd International Conference on Advances in Energy Engineering (ICAEE).
doi:10.1016/j.egypro.2011.12.1005

Nomenclature

$T_{i,a}$	Inside zone air temperature (°*C*)
$T_{o,a}$	Outside air temperature (°*C*)
T_{dg}	Deep ground temperature (°*C*)
L	Slab length (*m*)
B	Slab width (*m*)
W	Wall thickness (*m*)
E	Deep ground boundary depth (*m*)
F	Far field boundary distance (*m*)
q	Heat flux ($W.\ m^{-2}$)
$h_{,int}$	Internal convective heat transfer coefficient ($W.m^{-2}.K^{-1}$)
$h_{,ext}$	External convective heat transfer coefficient ($W.m^{-2}.K^{-1}$)
c_p	Specific heat capacity ($J.kg^{-1}.K^{-1}$)
k	Thermal conductivity ($W.m^{-1}.K^{-1}$)
ρ	Density ($kg.\mathrm{m}^{-3}$)

days is no more economically optimal. Therefore, actual tendency is in energy recovery via heat accumulation, more effective ventilation control, or using alternative fuels.

Publication [1] presents significant tendency in decreasing of energy consumption using numerical computing in building in recent years. The accuracy of these numerical tools has to be validated hence there is tendency in software benchmarking.

Three types of tests are recommended to evaluate accuracy of numerical models in [2]:

- Analytical verifications.
- Comparison with other models (comparative testing).
- Validation with experimental results (experimental validation).

There were created several software benchmarking methods in recent years. One of these benchmarks is Building Energy Simulation Test (BESTEST) provided by the International Energy Agency (IEA) in Task 34 [3]. There are mutually compared outputs from following software – BASECALC, EnergyPlus, ESP-r-BASESIMP, FLUENT, GHT, MATLAB, SUNREL-GC, TRNSYS, VA114-ISO13370 – in this benchmark. Presented benchmark is based on ground two-dimensional (2D) thermal conduction, long take time constants, and the heat storage of the ground.

Among software benchmarks, the most important requirements for building simulation software are:

- Stationary and transient simulation of heat and vapor transfer.
- Possibility to compute three-dimensional (or at least 2D) models to simulate local effects in constructions e.g. thermal bridges or corners.
- Simulation results should be reproducible and accessible.

COMSOL Multiphysics [4] simulation tool is validated in this article by comparative validation via Task 34. Created models of heat transfer via floor slab were simulated in two program versions (3.5a and 4.1) with minor result differences. The main program ability is based on numerical solving of partial differential equations by finite element method; hence its usage is wide as you can see in [5]. Nevertheless it was not been used for building simulation very often. The application of COMSOL Multiphysics model for building simulations can be found in [6].

2. Models description

There are 17 test cases specified in Task 34 while there were chosen 9 transient cases for this article. Individual cases are similar to each other with default model parameters depicted in Table 1. Outer temperature is described by harmonically varying sinusoidal diurnal temperature values with mean value 10°*C* and with low (season temperature cycle), respectively, high (daily temperature cycle) frequency temperature cycles.

Table 1. Default geometry and physicist parameters of the test cases

L	*B*	*W*	*Ti,a*	*To,a*	*Tdg*	*E*	*F*	$h_{,int}$, $h_{,ext}$	Floor and slab parameters		
									c_p	ρ	*k*
12	12	0.24	30	Various	10	15	15	100	1800	1490	1.9

Slab-on-grade test presented in Task 34 consists of 3 important test case categories:

- “a” series – allows to demonstrate that the numerical models have been properly applied.
- “b” series – allows to compare more detailed models (minor model differences).
- “c” series – uses boundary conditions compatible with the BASESIMP simulation software.

The “a” cases are in contrast to “b” or “c” cases computed analytically as well as numerically. Therefore they serve as primary test of simulation environment ability.

Schematic diagram of modeled geometry is showed in Fig. 1 – elevation zone dimensions are *L*x*B* with wall thickness *W*.

Presented cases drive floor conduction based on the temperature difference between zone air temperature and deep ground boundary condition with high vs. ordinary convective surface coefficients. The specific model differences in contrary to default values are described in Table 2 and following paragraphs.

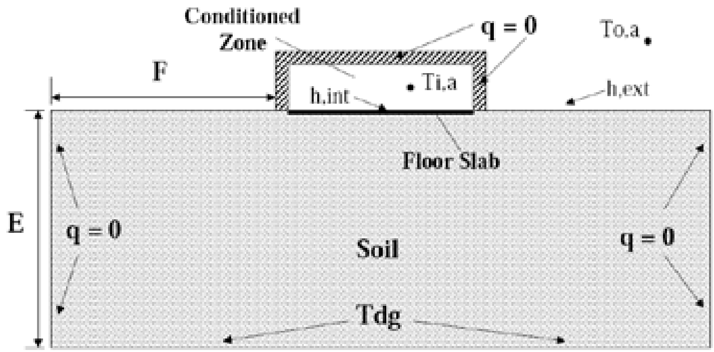

Fig. 1. Schematic model diagram with boundary parameters [3]

Table 2. Specific test case parameters

Test case	*LxB*	*E*	*F*	$h_{,int}$	$h_{,ext}$	*k*
GC40a	Default	30	20	Fixed T	Fixed T	Default
GC40b	Default	Default	Default	Default	Default	Default
GC40c	Default	15	8	7.95	Fixed T	Default
GC50b	80x80	Default	Default	Default	Default	Default
GC55b	Default	2	15	Default	Default	Default
GC55c	Default	5	8	7.95	Fixed T	Default
GC70b	Default	Default	Default	7.95	11.95	Default
GC80b	Default	Default	Default	Default	Default	0.5
GC80c	Default	15	8	7.95	Fixed T	0.85

Group cases GC40x analyze the phase shift between variation of heat flow and external temperature. Individual models differed in the value of Convective Heat Transfer Coefficient (CHTC) on internal zone boundary ($h_{,int}$) as well as on soil model surfaces ($h_{,ext}$).

Increased slab size caused in case GC50b massive ground heat transfer in comparison to the rest of cases, hence the GC50b bar of floor heat flow presented in Fig. 2 represents only 10% of calculated heat transfer value.

Cases GC55x represent the areas with a shallow groundwater table, which increases the effect of heat flow. Deep ground dimension is therefore changed to 33% (case GC55c) or 13% (case GC55b) of original model dimension.

Test GC70b uses original model dimension with realistic value of CHTCs on internal and external model boundaries.

Sensitivity to reduced slab and soil thermal conductivity is tested in test cases GC80x. The value of thermal conductivity is decreased to 50% in case GC80c and 26% in case GC80b.

3. Comsol Multiphysics Validation

It is important to stress out that the differences between simulation programs presented in following figure do not mean that one of them is better or worse. The only possible conclusion is that similar results imply high probability of correct program outputs.

The comparison of COMSOL Multiphysics with 9 already validated building energy simulation tools is showed in Fig. 2. The plot shows the sum of heat flow through room slab during one year period. It can be concluded that mean difference between COMSOL Multiphysics and other software results is about 4.8%. Two highest differences in floor conduction (7.7% and 10.2%) occurred in “c” test cases.

The differences between COMSOL Multiphysics results and mean value from tested software are showed in Table 3. The conductive heat flow through floor differs from 0.3% to 10.2% depending on the specific test case. The largest differences arise in cases: GC40c and GC80c. These cases are based on set temperature value on external ground boundaries and the usage of realistic value of CHTC on internal model boundary.

Comparison of the results from COMSOL Multiphysics with already validated software is depicted in Table 4. There are showed only programs in which is able to create minimally 5 from presented 9 models. The mean difference of currently used software is higher in contrast to Fluent or TRNSYS; nevertheless, EnergyPlus software, which was validated in [7], has the disagreement almost twice higher.

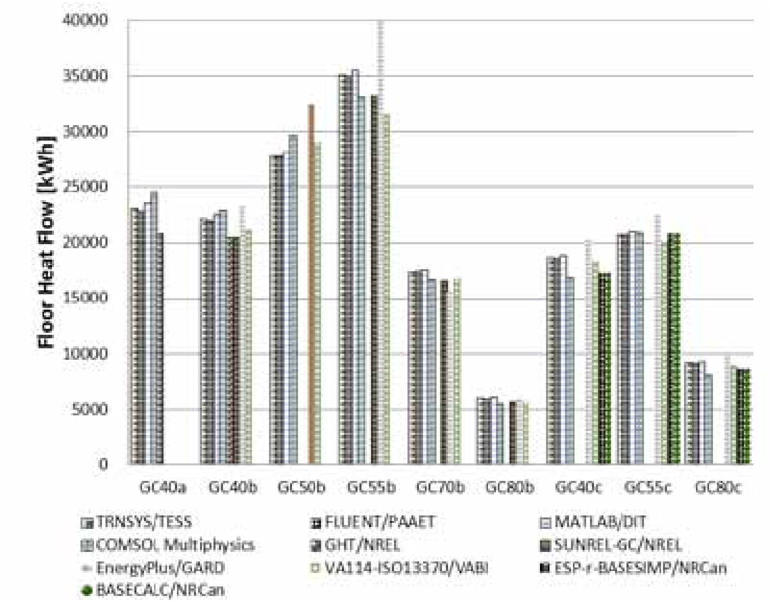

Fig. 2. Comparison the results of COMSOL Multiphysics and already validated software for building simulations

Table 3. Test case differences of COMSOL Multiphysics

Test case	*Heat flux difference*
GC40a	6.79 %
GC40b	4.57 %
GC50b	1.87 %
GC55b	4.76 %
GC70b	0.85 %
GC80b	5.75 %
GC40c	7.70 %
GC55c	0.25 %
GC80c	10.19 %

Table 4. Juxtaposition of several validated software with COMSOL Multiphysics

Name	*Mean difference*	*Standard deviation*
TRNSYS	2.01 %	1.25 %
Fluent	1.68 %	1.34 %
MATLAB	3.01 %	1.26 %
EnergyPlus	9.21 %	3.47 %
VA114-ISO13370	2.49 %	2.81 %
COMSOL Multiphysics	4.75 %	3.11 %

4. Conclusion

COMSOL Multiphysics were used to model transient ground-coupling models specified in IEA BESTEST Task 34 called “In-Depth Diagnostic Cases for Ground Coupled Heart Transfer Related to Slab-on-Grade Construction”. The results for 9 models of transient cases were compared to 9 programs which are already validated as building simulation software. The results similarity between COMSOL Multiphysics and already validated building simulation tools proves the program ability to calculate precise value of heat transfer in solving such problems.

Practical program application should definitely confirm COMSOL Multiphysics as one of the tools for precise building simulations. The experiment based on measurement in real building is challenging task for our future work.

Acknowledgements

The work behind the article was supported by the Ministry of Education of the Czech Republic under grant No. MSM 7088352102, by the European Regional Development Fund under the Project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089 and by the internal grant agency of Tomas Bata University in Zlin with NO. IGA/44/FAI/10/D, IGA/39/FAI/11/D and IGA/55/FAI/10/D.

References

[1] Schijndel AWM van, Schellen HL, Wijffelaars JL, Zundert K van. Application of an integrated indoor climate, HVAC and showcase, *Energy and Buildings* 2008, No. 40, 647–653, ISSN 0378-7788.

[2] Judkoff R, Neymark J. *International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method*; 1995, NREL/TP-472-6231, Golden, Colorado, US: National Renewable Energy Laboratory, www.nrel.gov/docs /legosti/old/6231.pdf.

[3] Neymark J, Judkoff R. *International Energy Agency Building Energy Simulation Test and Diagnostic Method (IEA BESTEST) – In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-On-Grade Construction*; 2008, NREL/TP-550-43388, Golden, Colorado, US: National Renewable Energy Laboratory, http://www.iea-shc.org/publications/downloads/task34-Building_Energy_Simulation_Test.pdf.

[4] COMSOL - Multiphysics Modeling and Simulation Software. *Multiphysics Modeling and Simulation Software*; 2011. http://www.comsol.com.

[5] Zimmerman WBJ. *Multiphysics Modelling with Finite Element Methods*. Ardéshir Guran. 1st edition. Singapore : World Scientific Publishing Co. Pte. Ltd., 2006. ISBN 10 981-256-843-3.

[6] Schijndel J. van. *Integrated Modeling using MatLab, Simulink and COMSOL: with heat, air and moisture applications for building physics and systems*. Saarbrucken: VDM Verlag Dr. Muller Aktiengesellschaft & Co. KG,. 2008. ISBN 978-3-639-10669-5.

[7] Henninger RH, Witte MJ. *EnergyPlus Testing with IEA BESTEST In-Depth Ground Coupled Heat Transfer Tests Related to Slab-on-Grade Construction*; 2010, NREL/TP-550-43388, Arlington Heights, Illinois, US: GARD Analytics, http://apps1.eere.energy.gov /buildings/energyplus/pdfs/energyplus_slab-on-grade_tests.pdf.