Ground-Coupled Heat Transfer Test Cases as ranking simulation software

Stanislav Sehnalek, Martin Zalesak, Jiri Vincenec, Michal Oplustil, Pavel Chrobak
Tomas Bata University in Zlin
Faculty of Applied Informatics
Nad Stranemi 4511,760 05 Zlin
Czech Republic
sehnalek@fai.utb.cz

Abstract: In the present work is International European Agency Building Energy Simulation Test Task 34 used as validation for SolidWorks Flow Simulation 2012. IEA BESTEST methodology is based on analytical verification of one model and on comparative validation of the rest of models. For appraisal was chosen 12 cases where half have stationary character and the remain half is periodical. In the beginning of the presented paper are described cases with appropriate application. The outcome of simulation follows with discussion about results which are segregated in the manner of periodic or steady character. The paper is wind up with outline of future research.

Key–Words: Heat transfer, Finite Element Method, SolidWorks Flow Simulation, Software validation, Benchmark, Building simulation.

1 Introduction

Share of glass used in faades of buildings is logarithmically increasing during the last two centuries. This results from some valuable features of glass, which are transparency, low weight and ability to separate different environments. Since Le Corbusiers era, glass is becoming dominant in usage for faades at the expense of conventional materials. This fact could prove Scheerbarts paraphrased words Bricks are only good to hurt. In the way of usage of glass for faades there is one important issue, which should be always taken into account. Temperature gains caused by internal and external heat sources. These gains affect comfort of people inside these plant house buildings. A long-term research of peoples comfort in 26 office buildings in five European Union countries was executed by [1]. Interior comfort can be provided by ventilation systems, by shading systems or by their combination, which are not always energetically sustainable. In recent years, there is a particular interest in sustainability of buildings [2] and [3]. Currently, there has been growing interest in lowering energy performance of buildings. This effort is also reflected in a new European directive, which instructs to construct near to zero energy sufficient buildings since year 2020. Regardless of our experience and knowledge, there are always a risks of constructing an inconvenient building. To prevent this, appropriate design of building should be achieved. Thermal properties of a building could be calculated in a development phase, but it is limited to one-dimensional and rarely as two-dimensional problem solutions thanks to the complexity of buildings and the mathematical apparatus available. As a result of computational power increase in last decades, it is possible to design a model and implement mathematical simulation of thermal behaviour of a building also in three-dimensional space [4]. For such mathematical simulation it is used finite element method (FEM) [5]. Thanks to the expanding performance of computers, FEM is used for partial differential equations solutions as a convenient way to validate building's behaviour [6]. However, first of all it is important to validate thermal simulation programs (DTSP) [7], which is used. The solution can be achieved by several ways. Judkoff and Neymark developed a methodology for such intention in the middle of 90s by [8]. Their approach is based on the analytical solution for steady-state heat flow through the floor slab. Although it was developed by Delsante, Stokes and Walsh [9], although this problem has been in focus of researchers for some time [10]. It is worth to mention a simplified model by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), which calculates slab-on-grade perimeter heat-loss, operates with perimeter length and an F-factor heat loss coefficient. Delsante's methodology focuses only on heat flow through floor slab and omits above grade constructions. Standard established by ASHRAE improved Judkoff's and Neymark's methodology by adding cases which focus mainly on above grade constructions and solar radiation [10], [11].

All mentioned methods and standards are based on finite element analysis (FEA). In this paper, an application of International European Agency Building Energy Simulation Test (IAE BESTEST) Task 34 is described on SolidWorks Flow Simulation (SW-FS). This task is already approved on DTSP like are TRNSYS, Fluent, EnergyPlus and ESP-r/BASESIMP. Besides that, investigation of COMSOL Multiphysics on Task 34 was done by Gerlich [12]. In the section methods is included outline of 6 cases from IAE BESTEST Task 34 along with a description of SW-FS. This chapter is followed by results section with description of implementation of cases on SW-FS and finally with results from simulation. Article is summarized by conclusion section with discussion about results which are segregated in the manner of periodic or steady character. The paper is concluded with outline of further research.

2 Methods

This section of the paper cover several topics and is divided in two parts. At the beginning of the section, Ground Coupling In-Depth Diagnostic Cases is described. More specifically: geometry, physical properties, initial conditions and boundary conditions. In the second section the outline capabilities of SolidWorks Flow Simulation 2012 SP5 (SW-FS) is listed.

2.1 IEA BESTEST cases

International Energy Agency Building Energy Simulation Test methodology was developed by [8] in the middle of 90's. Combination of empirical validation, analytical verification and comparative analysis techniques are main proceedings of this methodology. It operates only with slab-on-grade heat transfer and became a stepping-stone for the other approaches, such as ANSI/ASHRAE Standard 140 improved adaptation developed by ASHRAE accordingly with American National Standards Institute (ANSI).

Methodology describes 17 cases of ground-coupled heat transfers designed to be compared with verified whole-building energy simulation software. Several of those already tested by IEA are EnergyPlus, FLUENT, Matlab, TRNSys and GHT. The first case, GC10a has its base in analytical solution and it is the simplest one of all cases. Furthermore, these cases are subdivided into three series, each with its own specification. For this paper was chosen 12 cases where first half is steady-state and the rest is steady-periodic.

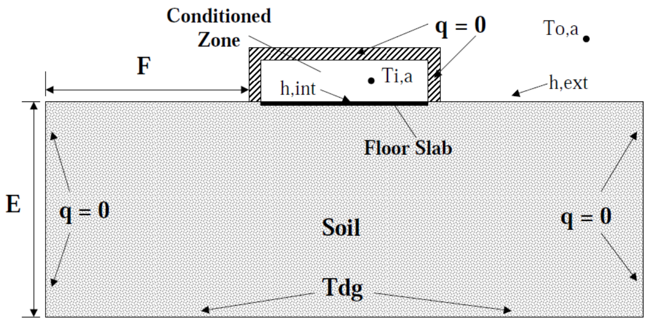

Figure 1: Elevation section (Neymark and Judkoff, 2008)

- Series a
  - The main purpose of this series is to use to validate whole-building simulation programs.
  - Namely: TRNSYS, SUNREL-GC, FLUENT and MATLAB.
  - It is recommended to apply this series as the first one, if a tested software can run it.
- Series b
  - In this series, parameters are adjusted for more limited whole-building simulation programs or standard.
  - Namely: EnergyPlus and ISO 13 370.
  - Provides basis for series a and c.
- Series c
  - This series is most narrowed in use of boundary conditions, because it serves only for comparison of BASESIMP with other software.

2.2 Geometry

Geometry is similar in most cases, except for several models, which will be described later. Figure 1 depicts the elevation section of the examined test model, where F represents far field boundary distance, E stands for deep ground boundary depth, Tdg is deep ground temperature, To, a is the outside air temperature, Ti, a is the inside temperature and $hint$ and $hext$ represents surface coefficients of convection [8].

Fig. 2 shows plan view of the proposed building with slab dimensions. These parameters are similar for all cases. The last dimension parameter worth mentioning is the height of the conditioned zone. Table 1 enlists geometrical properties for proposed cases, with inequality in GC10a, GC30a and GC30c,

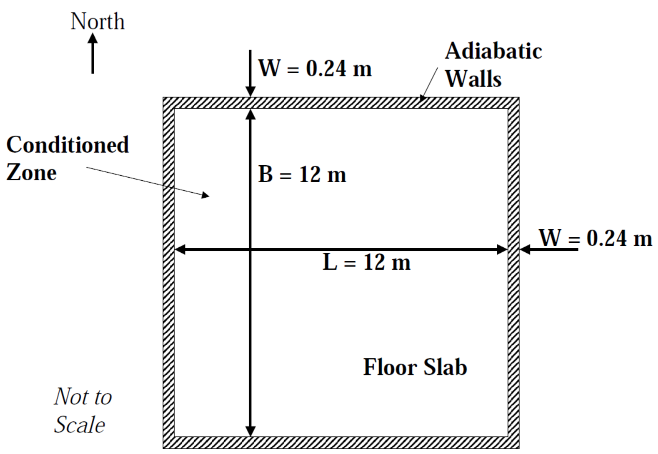

Figure 2: Plan view (Neymark and Judkoff, 2008)

Table 1: Geometry properties.

Parameter	Value [m]
B	12
E	15
F	15
L	12
W	0,24
Building height	2,7

which vary in ground depth and far-field boundary distance [8].

2.2.1 Thermal properties

Besides surface coefficients of convection, the rest of thermal properties are the identical for all test cases. These are enlisted in table 2 where surface coefficients of convection are applied on all surfaces with a value 100 $\mathrm{W\,m^{-2}\,K^{-1}}$, within exception of specific cases which are mentioned later.

Several parameters which are not present in table 2 also have to be taken into account: use slab thickness as low as software allows for a stable calculation; for software demanding below-grade foundation walls, use the same thermal properties as soil; surface radiation exchange is not included (if necessary set radiation to 0 or as low as possible); the ground surface and floor slab are on the same height level and both are considered to be flat and homogenous; for all cases water transmission via material should be turned off or reduced to its lowest level; adiabatic walls of the above construction are in contact with soil but do not penetrate it; no windows; no infiltration or ventilation; no internal gains.

Table 2: Thermal properties for soil, slab and above grade construction.

	Soil and Slab	Above-Grade Construction
Temperature [°C]	10	30
Convective surface coefficients [$\mathrm{W\,m^{-2}\,K^{-1}}$]	100	100
Thermal conductivity [$\mathrm{W\,m^{-1}\,K^{-1}}$]	1,9	0 or 0,000001
Density [$\mathrm{kg\,m^{-3}}$]	1490	0 or 0,000001
Specific heat [$\mathrm{J\,kg^{-1}\,K^{-1}}$]	1800	0 or 0,000001

If the software does not allow entering direct surface temperatures, user can apply very high surface coefficients of convection with ambient air temperature. It is recommended to set $h \geq 5000\mathrm{W\,m^{-2}\,K^{-1}}$ if the program allows such surface coefficient, if it be to the contrary use maximum h value that tested software accepts. In some cases such a great number can cause instability of some simulation software [8].

2.2.2 Weather data files

In contemplation of steady-periodic cases there are provided weather data in TMY2 format. For this purpose was used hourly temperature oscillation, which was approximate from annual cycle variation measured between 1961 and 1990. The weather station from which was artificial conditions generated is situated 25.8° North and 80.3° West, with 2 m altitude. External link to weather files is provided in [8].

2.3 Case specification

The list of used methods follows. Each case is specified and enlisted with changes against default configuration.

2.3.1 Case GC10a Steady-State Analytical Verification Base Case

Result from this case is verified by analytical solution method and comparison with test numerical simulation software can be considered as secondary mathematical truth standard. Such approach is beneficial for later cases, where exact analytical solution is unknown.

Changes to surface geometry is given

- This case has similar main geometrical and thermal properties with exception of dimension. In this case, ground surface is considered to be semi-infinite both in downward and horizontal direction.

This case is based on Analytical Solution for Steady-State Heat Flow through the Floor Slab in 3 dimensional space conditions, which was developed by [9]. The total heat flow through the slab into the ground is:

$$q = k(T_i - T_o)\frac{1}{\pi}F(L, B, W) \qquad (1)$$

Where:	T_i	is surface temperature of the floor
	T_o	surface temperature of the outside ground
	k	conductivity of floor slab and soil
	$F(L, B, W)$	dimension function of L,B and W

2.3.2 Case GC30a Steady-State Comparative Test Base Case with Direct Input of Surface Temperatures

This test case method compares steady-state heat flow results with verified numerical-model results. In this case surface boundary conditions could be tricky for some simulation software. Comparison of this case with GC10a (GC30aGC10a) reveals the sensitivity to perimeter surface boundary.

Changes to surface geometry are given

- Deep ground boundary depth E = 30 m
- Far-field boundary distance F = 20 m

2.3.3 Case GC30b Steady-State Comparative Test Base Case

Steady-State Comparative Test is used to compare temperature divergence of zone air and ambient air with a use of adiabatic zone interface boundary. This case compares GC30a (GC30bGC30a) checking sensitivity to steep surface coefficients of convection versus direct-input surface temperature boundary.

Changes to surface parameters are given

- $h_{,int}$ = 100 W m^{-2} K^{-1}
- $h_{,ext}$ = 100 W m^{-2} K^{-1}

2.3.4 Case GC40a Harmonic Variation of Direct-Input Exterior Surface Temperature

This is a first case which use steady-periodic conditions for outer surface temperature. Aim of this case is to analyze phase drift between heat flow and outer temperature. To check sensitivity of SW-FS to floor heat loss with harmonic conditions against steady-state conditions is recommended to compare this case with GC30a (GC40aGC30a).

Changes to surface geometry are given

- Deep ground boundary depth E = 30 m
- Far-field boundary distance F = 20 m

2.3.5 Case GC40b Harmonic Variation of Ambient Temperature

This case is similar to GC30b with exception that it use periodic conditions. Sensitivity to harmonic conditions to the contrary to steady conditions is checked by comparing this case with GC30b (GC40bGC30b).

Changes to thermal properties are given

- $h_{,int}$ = 100 W m^{-2} K^{-1}
- $h_{,ext}$ = 100 W m^{-2} K^{-1}

2.3.6 Case GC45b Aspect Ratio

Objective of this case is to validate sensitivity of aspect ratio with harmonic outside temperature variation. With use of dimensions in this case is soil relatively thin against perimeter. This affects perimeter heat transfer to core heat transfer. Sensitivity to aspect ratio will be check by comparison of this case with GC40b (GC45b-GC40b).

Changes to surface geometry are given

- Slab length L = 36 m
- Slab width B = 4 m

2.3.7 Case GC50b Large Slab

Purpose of this case is to verify the sensitivity of slab size with steady-periodic conditions. Amplification of the slab size generate large portion of heat transfer between slab and deep ground temperature. Result of this case will be compared with GC40b (GC50bGC40b) for this purpose is eligible to normalize floor area. Such comparison is useful for validate sensitivity to heat transfer produced by magnified slab area.

Changes to surface geometry and thermal properties are given

- Slab length L = 80 m
- Slab width B = 80 m
- $h_{,int}$ = 100 $\mathrm{W\,m^{-2}\,K^{-1}}$
- $h_{,ext}$ = 100 $\mathrm{W\,m^{-2}\,K^{-1}}$

2.3.8 Case GC60b Steady State with Typical Interior Convective Surface Coefficient

In this case more realistic interior convective surface heat transfer coefficient is used. Zone floor surface temperature will be barely identical when more realistic coefficient is used. Also, increment in outward temperature in direction from the center can be expected. This case will be compared with result from GC30b (GC60bGC30b) to check sensitivity of decreased h.

Changes to thermal properties are given

- $h_{,int}$ = 7.95 $\mathrm{W\,m^{-2}\,K^{-1}}$)
- $h_{,ext}$ = 100 $\mathrm{W\,m^{-2}\,K^{-1}}$

2.3.9 Case GC65b Steady State with Typical Interior and Exterior Convective Surface Coefficients

With this case is used similar conditions as with GC60b only taking account one exception and that is lower h,ext. Similar increment in outward temperature can be estimated and results from this case will be compared with GC60b (GC65bGC60b), where sensitivity on h,ext is compared. And also will be compared result with GC30b (GC65bGC30b) where compared sensitivity on h,ext and h,int are checked.

Changes to thermal properties are given

- $h_{,int}$ = 7.95 $\mathrm{W\,m^{-2}\,K^{-1}}$
- $h_{,ext}$ = 11.95 $\mathrm{W\,m^{-2}\,K^{-1}}$

2.3.10 Case GC70b Harmonic Variation of Ambient Temperature with Typical Interior and Exterior Convective Surface Coefficients

More realistic thermal properties are used in this steady-periodic case. So sensitivity of more realistic heat convection coefficient can be tested. Comparing this case with GC65b (GC70bGC65b) will provide difference between steady-state and harmonic configuration.

Changes to thermal properties are given

- $h_{,int}$ = 7.95 $\mathrm{W\,m^{-2}\,K^{-1}}$
- $h_{,ext}$ = 11.95 $\mathrm{W\,m^{-2}\,K^{-1}}$

2.3.11 Case GC80b Reduced Slab and Ground Conductivity

Last case from series b test behavior with reduced slab and ground conductivity. It verify sensitivity to slab and ground conductivity by comparing with GC40b (GC80bGC40b).

Changes to thermal properties are given

- k = 0.5 $\mathrm{W\,m^{-1}\,K^{-1}}$

2.3.12 Case GC30c Steady-State Comparative Test Base Case with BASESIMP Boundary Conditions

Purpose of this case is to compare numerical simulation programs of boundary conditions compatible with BASESIMP. With this model will be comparison of GC30b (GC30cGC30a) to check reduced interior surface coefficient sensitivity.

Changes to surface geometry and thermal properties are given

- Far field boundary distance F = 8 m
- $h_{,int}$ = 7.95 $\mathrm{W\,m^{-2}\,K^{-1}}$

2.4 SolidWorks Flow Simulation

SolidWorks Flow Simulation 2012 (SW-FS) is a fluid flow analysis add-in package that is available for SolidWorks in order to obtain solutions to the full Navier-Stokes equations that govern the motion of fluids. SW-FS is tool which can be used for wide range of fluid flow and heat transfer studies. Some of physical calculation capabilities are [13]:

- External and internal fluid flows
- Steady-state and time-dependent fluid flows
- Fluid flows with boundary layers, including wall roughness effects
- Multi-species fluids and multi-component solids
- Heat conduction in fluid, solid and porous media with/without conjugate heat transfer and/or contact heat resistance between solids and/or radiation heat transfer between opaque solids (some solids can be considered transparent for radiation), and/or volume (or surface) heat sources, e.g. due to Peltier effect
- Joule heating due to direct electric current in electrically conducting solids
- Various types of thermal conductivity in solid medium, i.e. isotropic, unidirectional, biaxial/axisymmetric, and orthotropic
- Fluid flows and heat transfer in porous media
- Periodic boundary conditions

2.4.1 The Navier-Stokes Equations for Laminar and Turbulent Fluid Flows

SW-FS are solving Navier-Stokes equations formulated with mass, momentum and energy conservation laws. They are supplemented with nature of the fluid and with empirical dependencies of fluid density, viscosity and thermal conductivity. Finally the definition of geometry, boundary and initial condition is specifying particular problem.
Several boundary conditions can be setup. Internal Flow Boundary Conditions can be managed as same as External Flow Boundary Conditions. The last of three is Wall Boundary Conditions that can be managed as impermeable in case of solid walls. There is also option to manage wall as Ideal Wall, which corresponds to the well-known slip condition.
SW-FS employed numerical solution technique so it is usable for less knowledge about the computational mesh and numerical methods. But there are also included options to adjustment values of parameters governing the numerical solution technique to lover computer resources or to provide superior results. Finite volume method is used on a cubic Cartesian coordinate system with planes orthogonal to its axes. If it is necessary can by refined locally in specific region during calculation [13].

Mesh in SW-FS is rectangular everywhere in the computational domain. That means that cells sides are orthogonal to specific axes. That means that boundary between fluid and solid may have partial cells. The computational mesh is constructed in the several stages. Basic mesh is constructed firstly, dividing computational domain into slices where user can specify number and spacing of the planes in each axes. Intersection between solid and fluid are divided uniformly into smaller cells to provide more appropriate result in this boundary. Meshing procedures are executed before the calculation so SW-FS is unable to resolve all solution features well. To abandon this disadvantage there is option during the calculation to change mesh in accordance with the solution spatial gradients. That means that regions with high-gradient are divided in more cells while in low-gradient regions are cells merged. This feature is called refinement and it can be imposed manually or automatically, at any state of the calculation process [13]. Validation examples can be found in documentation [14] or elsewhere [15].

3 Results

Result section will provide outcome of appropriate application of IEA BESTEST cases on SW-FS software and findings will be discussed in the following part of the chapter.

Table 3: Stationary test cases calculated by SW-FS.

Case	Solid Works [W]	Average [W]	Absolute difference [W]	Relative difference [%]
GC10a	2417	2432	15	1
GC30a	2552	2567	15	1
GC30b	2488	2499	11	<1
GC30c	2125	2161	36	2
GC60b	2097	2127	29	1
GC65b	1984	1914	70	4

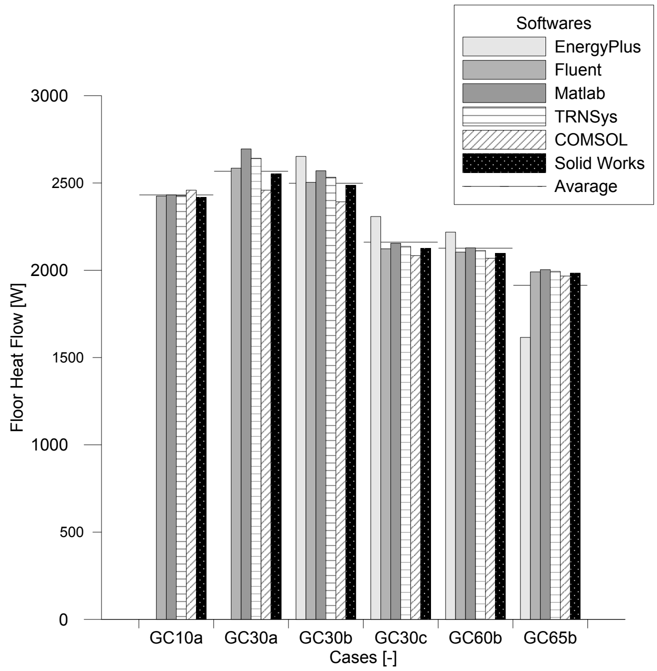

Figure 3: IEA BESTEST Ground Coupling: In-Depth Floor Slab Steady-State Floor Conduction.

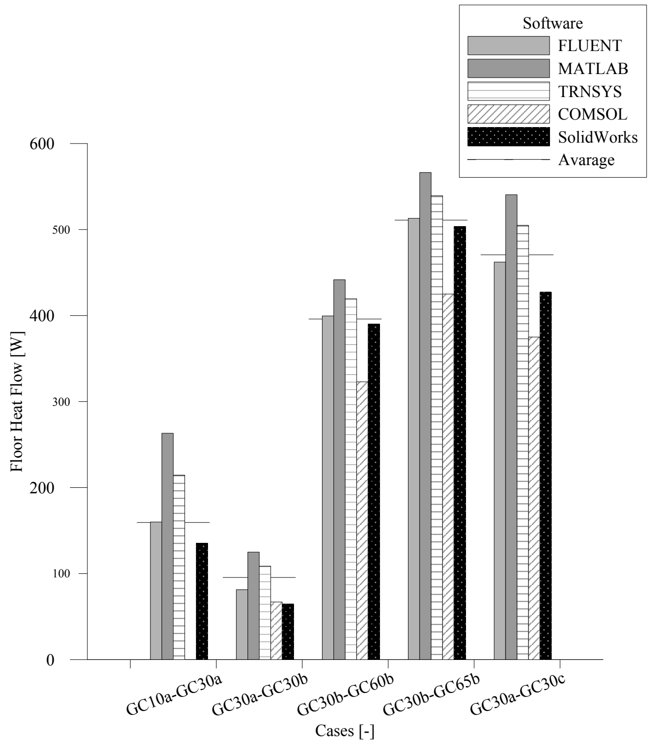

Figure 4: IEA BESTEST Ground Coupling: In-Depth Floor Slab Steady-State Floor Conduction Sensitivity

3.1 Application of cases on SW-FS

This chapter deals with implementation of IEA BESTEST on SW-FS. Cases main parameters initiation will be provided in subsections. First case is considered as parental for all the other cases and only changes in those will be mentioned.
Geometry model was established as assemblies in SolidWorks consisting of three parts. These are soil, slab and Above-Grade Construction (cubicle), and each part corresponds with models physical property. They were modelled from centre of the Cartesian coordinates and mates together. A new project in Flow Simulation by Wizard tool was created for simulation. Selection of Unit Systems, in this case SI units, follows the choice of appropriate name. The only change made was a switch on temperature; from K to C. Heat conduction in solids as the only option was selected for external analysis type. For a default solid material was created a new entry in the Engineering database with thermal properties of soil and slab described in Table 2. Initial conditions of solid parameters were changed form 20 C to 10 C. The last adjustment in Wizard tool was made on initial mash, which was set to 8 along with manual input of gap size value 2.7m and wall thickness 0.24m. Setup of the study continues with an insertion of thermal properties for the cubicle. This can be done by Solid Material option and by creating a new entry in the Engineering database together with a selection of appropriate geometry. Boundary conditions were established separately for each surface with an entry of appropriate convective surface coefficients and fluid temperature. Finally, computational goals were selected.

3.2 Steady-state results

After appropriate setup of the cases on SW-FS simulation of each case was executed. Results from sim-

Table 4: Stationary test case comparison calculated by SW-FS.

Case	Solid Works [W]	Average [W]	Absolute difference [W]	Relative difference [%]
GC10a -GC30a	135	159	24	15
GC30a -GC30b	65	95	31	32
GC30b -GC60b	390	396	6	1
GC30b -GC65b	504	511	7	1
GC30a -GC30c	427	471	43	9

ulation are shown in Fig. 3. Axis Y represents heat flows in Wats, on axis X are displayed used cases. The line at the top of each case is average without SW-FS taken in account. Results for EnergyPlus, FLUENT, Matlab and TRNSYS was taken from [8], results for COMSOL Multiphysisc was taken from [12]. Results of case GC10a and GC30a was not provided for EnergyPlus.

As can be seen in Fig. 3, results of SW-FS vary from average by small percentage. Only in case GC10a is result lower than was desirable, particular because this case is validate by analytical solution. This difference could be cost by impossibility to make the perimeter infinite. The rest of cases achieved satisfactory values, which differ almost in all instants by 1% and case GC65b differ in positive direction almost by 4% as reveals table 3.

Comparison of cases is displayed in Fig. 4 . Axis Y is similar to Fig. 3, axis x represents odds between cases. Values were taken from same source as for Fig. 3. For this comparison was EnergyPlus excluded because of missing results in cases GC10a and GC30a. The evaluation for this comparison is presented in table 4. As can be seen difference vary from approximately 1% to 32%. Difference between cases GC10a GC30a in about 15% reveals that the sensitivity to perimeter boundary of SW-FS is slightly worse than it should be. The comparison of GC30a GC30b illustrates that SW-FS is imbalance for steep surface coefficients. On the other hand sensitivity to decreased h is very positive, which proves comparison of cases GC30b - GC60b and GC30b - GC65b.

During the simulation preparation phenomenon of SW-FS have been discovered. That is inappropriate behavior when SW-FS refining the mesh. When settings of mesh and refinement kept on default, software are generates basic mesh properly, after several iteration it starts to refine and phenomenon occur. Several options were changed along with geometry to figure what this asymmetry causing, without positive answer. For the proper calculations was mesh configured manually to obey automatic refinement problem. This was done by control planes, which divide geometry to parts and then spread mesh between. The appropriate settings, which were use, can be find in table 5 . The comparison of basic mesh with refined mesh is depicted in Fig. 5 . Basic mesh had totally 38 400 cells, where in direction X and Z had 40 cells and direction Y had 24 cells. After refinement, number of cells increased to 331 553.

Fig. 7 represent heat flux on interior and exterior ground surface from top view. Values reaching more than 83 W/m2 in corners of above-grade construction in opposition to exterior surface where reaching almost zero.

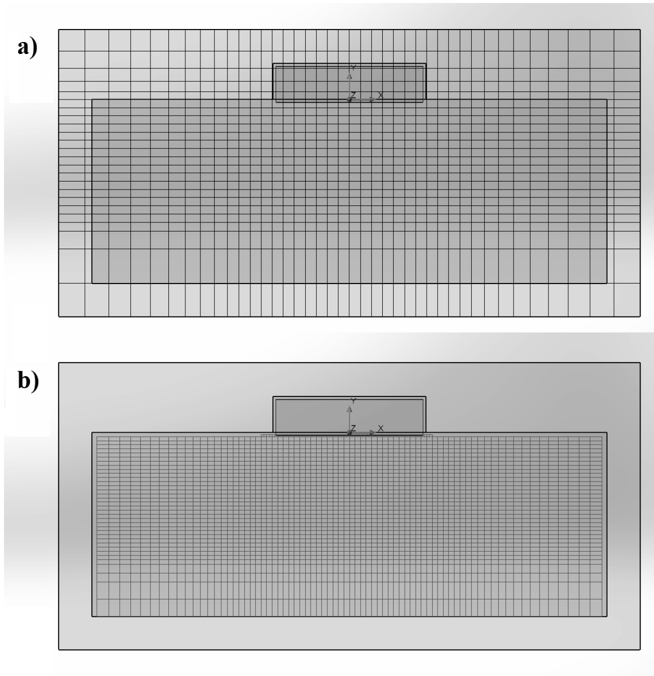

Figure 5: Generated mesh by manual settings: a) basic mesh, b) refined mesh for solids.

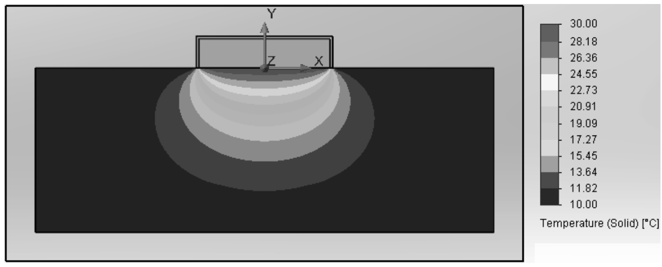

Figure 6: Side view of temperature distribution.

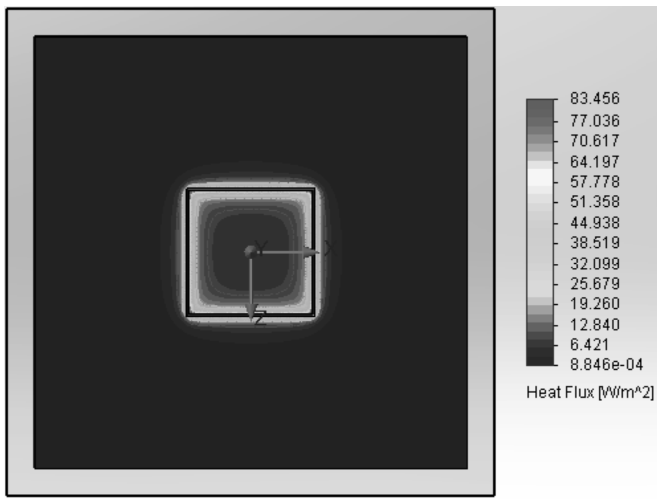

Figure 7: Top view of heat flow.

Table 5: Control planes settings.

	Name	Minimum	Maximum
Control planes in X direction	X1	-23,7	-10
	X2	-10	10
	X3	10	23,7
	Name	**Minimum**	**Maximum**
Control planes in Y direction	Y1	-17,7	-10
	Y2	-10	-3
	Y3	-3	0
	Y4	0	5,6
	Name	**Minimum**	**Maximum**
Control planes in Z direction	Z1	-23,7	-10
	Z2	-10	10
	Z3	10	23,7

Side view of temperature distribution is disclosed in Fig. 6. This state is for case GC30b with basic conditions. Other cases are similar only with little differences in distribution and geometry sizes. Displayed temperature are in °C and vary from 10 °C for exterior to 30 °C for investigated slab.

3.3 Steady-periodic results

With this suite of cases refinement phenomenon was not enroll so mesh settings was kept on automatic options. Also due to enormous storage consumption quarter of computational domain was calculated. Symmetry in X and Z dimension was taken in action. Storage consumption for each case is summarized in table 6. From the table is clear that case GC50b consumed bulk of storage, while case GC40b used minor amount. There is no clear key to predict what amount of storage space will be needed for simulation before run.

Table 6: Summary of periodical cases.

Case	Condition satisfaction [Year]	Storage consumption [GB]
GC40a	19	19,4
GC40b	7	17,7
GC45b	12	20,7
GC50b	22	143,4
GC70b	8	24,9
GC80b	13	49,5

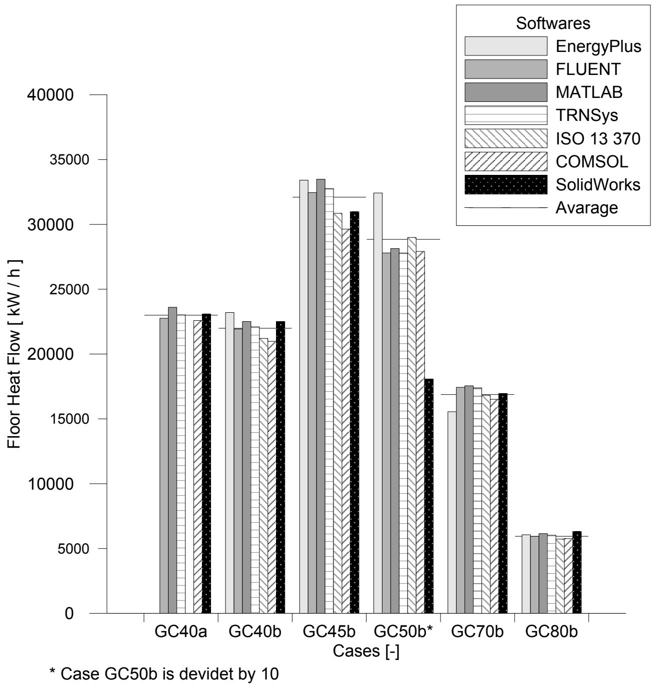

Figure 8: IEA BESTEST Ground Coupling: In-Depth Floor Slab Steady-Harmonic Floor Conduction.

Output Requirements It is specified by IEA BESTEST to run steady-periodic simulations as long as it is require to satisfy condition that last hour of the year is less or equal by 0,1% than last hour in previous year. Prospect for how many years calculation take account until this condition was satisfy is in table 6 .

Outcome of harmonic cases is revealed in Fig. 8. Axis are similar to that in steady-state part, with one exception and that is that axis Y is in kW h due to it harmonic nature.

The sensitivity between cases is plotted in Fig. 9. Results for case GC40a was not provided for EnergyPlus and ISO 13 370. As was mentioned earlier it is crucial to normalize floor are of GC50b. That can be accomplished in the event that it is divided by (80 * 80) * (12 * 12).

4 Conclusion

The results indicate, overall, that SW-FS is capable of mathematical simulation of heat flow through the floor slab. Variation of 1% to 4% is very positive for such type of benchmark. As is documented in [8], there was variety from 9% to 55% disagreement between firstly tested software with the analytical solution. Afterwards improvement in software lowering that difference to the highest value of 24%. Although version of SW-FS was 2012 and in present time is ver-

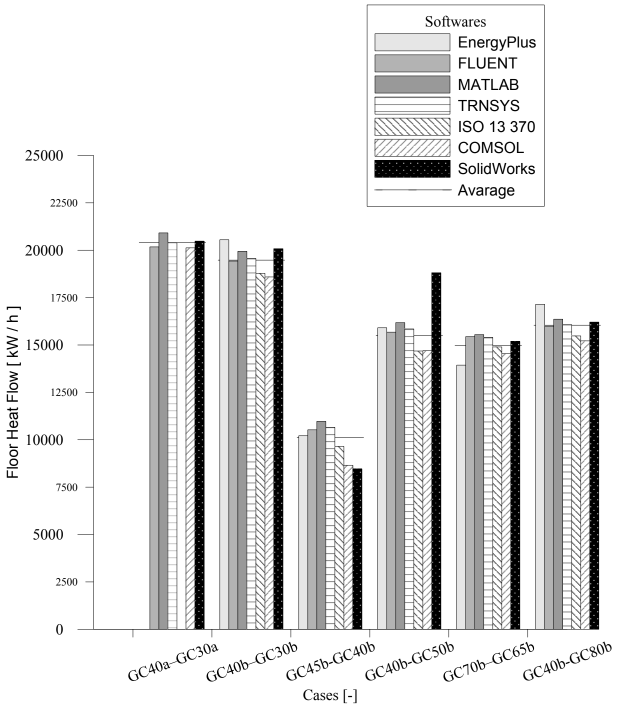

Figure 9: IEA BESTEST Ground Coupling: In-Depth Floor Slab Steady-Harmonic Floor Conduction Sensitivity.

sion 2014 on the market, it would be interesting to benchmark and compare results of that version with tested version.

However, appropriate setup of mesh should be considered along with proper analysis after generation. Also refinement option should be acknowledge as results showed big differences. Interest with refinement should be also in symmetrical object where SW-FS showed high disproportions.

The second part of results section contained sinusoidal variation of outside temperature. Outcome show some surpassing variations in results. Mostly with case GC50b where difference between SW-FS and average was 43%. This could be caused by the fact that mesh was kept on automatic generation and was not accordingly precise. Also the fact that it took 22 years before it achieved 0.1% difference supports the mesh idea. The rest of cases are in less then 10% variation. When it comes to sensitivity, SW-FS demonstrate also good variation to average.

Further research should aim comprehensive ANSI/ASHRAE Standard 140, and properly validate SW-FS with it. Although, SW-FS is not mainly for building applications, there is no snag why not to use it for such industry. Moreover as results prove it is suitable and in some cases more than other software adjusted mainly on it.

Table 7: Periodical test cases calculated by SW-FS.

Case	Solid Works [W]	Average [W]	Absolute difference [W]	Relative difference [%]
GC40a	23096	22997	99	<1
GC40b	22515	21989	526	2
GC45b	30977	32101	1125	4
GC50b	16467	28845	12378	43
GC70b	16962	16877	85	<1
GC80b	6306	5945	361	6

Table 8: Periodical test cases comparison calculated by SW-FS.

Case	Solid Works [W]	Average [W]	Absolute difference [W]	Relative difference [%]
GC40a -GC30a	20481	20401	79	<1
GC40b -GC30b	20080	19477	603	3
GC45b -GC40b	8462	10112	1650	16
GC40b -GC50b	18810	15499	3312	21
GC70b -GC65b	15187	14962	225	2
GC40b -GC80b	16209	15478	164	1

Acknowledgements: This work was supported in frame of Internal Grant Agency of Tomas Bata University in Zlin, Faculty of Applied Informatics IGA/FAI/2014/015, IGA/FAI/2014/047, IGA/FAI/2014/050, and IGA/FAI/2014/057 and under the project CEBIA-TECH NO. CZ.1.05/2.1.00/03.00089

References:

[1] Nicol, F. and Humphreys, M. (2007). Maximum temperatures in European office buildings to avoid heat discomfort, Solar Energy 81(3): 295304.

[2] Butera, F. M. (2004). Glass architecture : is it sustainable ?, Passive and Low Energy Cooling for the Built Environment, number May 2005, Santorini, pp. 161168.

[3] Poirazis, H. (2004). Double Skin Facades for Office Buildings Literature Review, Technical report, Lund.

[4] Tsai, B.-j., Lin, S.-C. and Yang, W.-C. (2012). HVAC analysis of a building installed shape-stabilized phase change material plates coupling an active building envelope system, WSEAS TRANSACTIONS on HEAT and MASS TRANSFER 7(3): 7990.

[5] Chereches, M., Popovici, C. and Chereches, N.-C. (2010). Experimental and Numerical Approach of the Thermal Conductivity of Building Facade Materials, WSEAS TRANSACTIONS on HEAT and MASS TRANSFER 5(3): 103112.

[6] Jarungthammachote, S. (2014). Entropy Generation Analysis of Transient Heat Conduction in a Solid Slab with Fixed Temperature Boundary Conditions, WSEAS TRANSACTIONS on HEAT and MASS TRANSFER 9: 918.

[7] Lomas, K., Eppel, H., Martin, C. and Bloomfield, D. (1997). Empirical validation of building energy simulation programs, Energy and Buildings 26(3): 253275.

[8] Neymark, J. and Judkoff, R. (2008). In-Depth Diagnostic Cases for Ground Coupled Heat Transfer 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, Technical Report September 2008, NREL, Golden.

[9] Delsante, A. (1987). The Development of an Hourly Thermal Simulation Program for Use in the Australian Nationwide House Energy Rating Scheme.

[10] Trethowen, H. and Delsante, A. (1998). Four-Year On-Site Measurement of Heat Flow in Slab-on-Ground Floors with Wet Soils, Thermal performance of the exterior envelopes of buildings VII(December): 487499.

[11] Judkoff, R. and Neymark, J. (2006). Model Validation and Testing : The Methodological Foundation of ASHRAE Standard 140, Technical report.

[12] Gerlich, V., Sulovska, K. and Zalesak, M. (2013). COMSOL Multiphysics validation as simulation software for heat transfer calculation in buildings: Building simulation software validation, Measurement 46(6): 20032012.

[13] Das (2012b). SoliddWorks Flow Simulation 2012 Technical Reference. Dassault Systemes SolidWorks Corp.

[14] Das (2012a). SoliddWorks Flow Simulation 2012 Solving Engineering Problems with Flow Simulation 2012. Dassault Systemes SolidWorks Corp.

[15] Matsson, J. E. (2012). An Introduction to SolidWorks Flow Simulation 2012, Schroff Development Corporation.