COMSOL Multiphysics for building energy simulation (BES) using BESTEST criteria

D.P.M. Jacobs and A.W.M. van Schijndel*
Eindhoven University of Technology, Netherlands
*Corresponding author: P.O. Box 513 Eindhoven Netherlands, A.W.M.v.Schijndel@tue.nl

Abstract: An overall objective of energy efficiency in the built environment is to improve building and systems performances in terms of durability, comfort and economics. In order to predict, improve and meet a certain set of performance requirements related to the indoor climate of buildings and the associated energy demand, numerical simulation tools are indispensable. In this paper we consider two types of numerical simulation tools: Finite Element Method (FEM) and Building Energy Simulation (BES). A well known benchmark case for BES, the so-called BESTEST, is used to verify Comsol (FEM) 3D simulation results. It is concluded that one of the main benefits of FEM-BES modeling exchange is the possibility to simulate building energy performances with high spatial resolution.

Keywords: Building, energy, performance, Comsol, FEM, BES

1. Introduction

An overall objective of energy efficiency in the built environment is to improve building and systems performances in terms of durability, comfort and economics. In order to predict, improve and meet a certain set of performance requirements related to the indoor climate of buildings and the associated energy demand, numerical simulation tools are indispensable. van Schijndel and Kramer (2013) consider three types of numerical simulation tools: Finite Element Method (FEM), Building Energy Simulation (BES) and State-Space (SS). For each tool separately, there exist a vast number of references. Also on two tools combined, i.e. FEM-BES, BES-SS, FEM-SS, there is quite a lot of literature. However there is lack of research on an overall evaluation of the three tools FEM-SS-BES together. In this paper we present benefits of the FEM-SS-BES modeling exchange for building physics. The main reasons for converting models in each other are summarized in Table I.

Table I. The main reasons for converting models in each other

From \ To	FEM	BES	SS
FEM	*	Global effects Lumped results	Computation Speed
BES	Local effects High resolution results	*	
SS		Inverse Modeling	*

van Schijndel and Kramer (2013) conclude that is seems to be possible to accurately reproduce a BES simulation using a relative simple heat conduction based FEM model with a equivalent heat conduction coefficient for the indoor air, but so far without CFD and internal radiation. This paper proceeds on this previous work by applying a well known benchmark case for BES, the so-called BESTEST, to verify the above mentioned described method.

2. The BESTEST

The Bestest (ASHRAE 2001) is a set of well documented test cases for software-to-software comparisons and program diagnostics. Good results make it likely that there are no severe internal (programming) errors and that the assumptions made are justified.

The cases selected were: Case 600FF: lightweight structure, base case, free floating temperature; Case 900FF: heavyweight structure, base case, free floating temperature; Case 600: lightweight structure, base case, heating and cooling system and Case 900: heavyweight structure, base case, heating and cooling system.

The test building is represented in Figure 1 (windows are facing south).

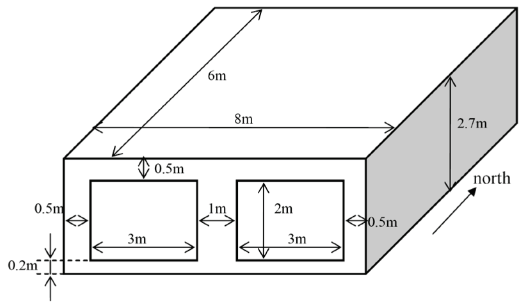

Figure 1. Bestest Case Geometry

The original weather data supplied for the Bestest site are based on a weather station located at 39.8° latitude with cold clear winters (min. -24 °C) and hot dry summers (max. 35 °C). *However in this work, we use weather data from DeBilt Netherlands, the rest was kept the same.*

3. Use of COMSOL Multiphysics

In previous research by A.W.M. van Schijndel (2013), a COMSOL Multiphysics model was developed to simulate the thermal behaviour of a small box. In this research, this model is used as a base model. It is expanded in several steps towards the BESTEST case 600 model. In each step, one parameter in the model is changed or a feature is added. These steps are described separately in this paragraph.
The simulated time is 31 days (744 hours), from the first of January 00:00u until the 31st of January at 24:00u. The period of one month is long enough to clearly compare the results from COMSOL Multiphysics to the results of HAMBase and the simulation time is such that the simulations could be done within the half year window within which this research needed to be complete.

Solar radiation
Solar radiation has not been taken into account in this research. Therefore in both the HAMBase model and the COMSOL model the solar radiation was either removed or disabled.

Climate
In the model, the climate file for DeBilt (1981) was used. This climate file was substituted by the climate file from Denver USA, which is used in the BESTEST model. (see Figure 2).

Façade
The construction of the BESTEST simulation is build up out of 3 layers, with exception of the floor, which has 2 layers.

Volume
The BESTEST simulation has a volume of 2.7x6x8 m.

Ventilation
In the BESTEST model, a ventilation of 0.5 ACH needs to be modeled. The total power of the ventilation is determined by the amount of energy that is gained or lost by replacing an amount of interior air with exterior air. This is done by calculating a mass flow, as shown:

$$mdot = \frac{ACH * v * \rho}{3600} \quad [1]$$

mdot:	mass flow	[kg/s]
ACH:	air change rate	[1/hr]
v:	volume	[m^3]
ρ:	density of air	[kg/m^3]

The amount of energy that is involved in this mass flow can be calculated using:

$$\text{Pv} = \text{mdot} * \text{c} * (T_{ex} - T_{in}) \quad [2]$$

Pv:	total power of the ventilation	[W]
c:	specific heat of air	[J/kg*K]
T_{ex}:	exterior temperature	[K]
T_{in}:	interior temperature	[K]

As can be seen, the total power of ventilation (Pv) can be both positive and negative depending on the interior and exterior temperature.
In the COMSOL model, volume of 1 m^3 (1*1*1 m) is placed in the middle of the room. The addition or extraction of heat from the room as a result of ventilation is done in this volume. The volume is placed in the middle of the room to ensure even distribution of the added or extracted heat over the room. The average hourly temperature of both the room and this volume inside the room is taken and compared to the

Heating and cooling
Heating and cooling needs to be modeled for the BESTEST. For heating, the amount of heat that needs to be added to the room in order to get the

room temperature to the minimum temperature that is required, is calculated using the .

$$Ph = if\ T_{in} > T_{min}, then\ 0, \quad else\ (T_{min} - T_{in}) * \rho * c * v \qquad [3]$$

Ph: total power of the heating [W]
T_{min}: minimum set temperature [K]

This capacity is calculated for every hour of the simulation and added to the same 1 m^3 volume as was discussed in 'Ventilation'. A similar formula is made for the cooling capacity:

$$Pc = if\ T_{in} < T_{max}, then\ 0, \quad else\ (T_{max} - T_{in}) * \rho * c * v \qquad [4]$$

Pc: total power of the heating [W]
T_{max}: maximum set temperature [K]

Also this capacity is added to the 1 m^3 volume in the middle of the simulated room in COMSOL

Windows
The BESTEST-model contains two windows in the south façade which consist of double glazing. These windows are too thin to be modeled in COMSOL, because the mesh would become too fine. There for, the window has been replaced with a volume with the same thickness as the wall.

Energy consumption
When actively heating and/or cooling is simulated, the outputs of the energy consumption of this heating and/or cooling can be obtained as described below. The energy consumption can be calculated in COMSOL in 'Results -> Derived values -> General Evaluation' by filling in Equation 3 in 'Expression'. This way, the heating capacity in W is calculated over time to get the energy consumption.

4. Results

The results from every simulation described above will be shown in a graph. The results of the COMSOL models and the HAMBase models for each simulation will be shown in the same graph. Hereby, it is easy to visually check to what extend the simulations match.

4.1 BESTEST climate

After changing the climate from De Bilt to Denver USA in both the HAMBase model and the COMSOL model, both simulations were done.

Parameter	Simulated as in:
Climate	BESTEST
Façade	Annex 58
Volume	Annex 58
Ventilation	Annex 58
Heating and cooling	Annex 58
Windows	Annex 58

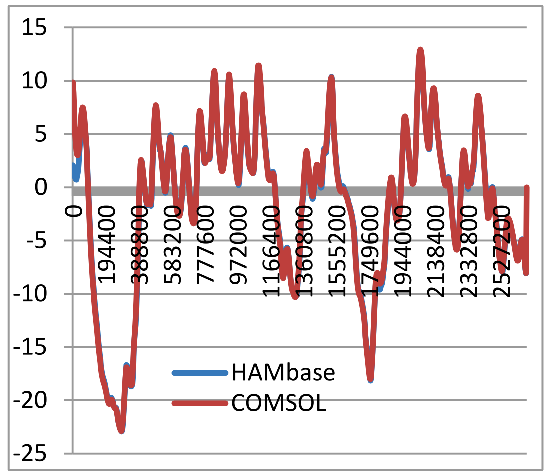

Figure 2 Interior temperatures over time as simulated in HAMBase and COMSOL, climate.

4.2 BESTEST climate and façade

After changing the climate and changing the façade from a single layer to a double or triple layer, depending on whether it concerned the floor, a wall or the roof, in both the HAMbase model and the COMSOL model, both simulations were done.

Parameter	Simulated as in:
Climate	BESTEST
Façade	BESTEST
Volume	Annex 58
Ventilation	Annex 58
Heating and cooling	Annex 58
Windows	Annex 58

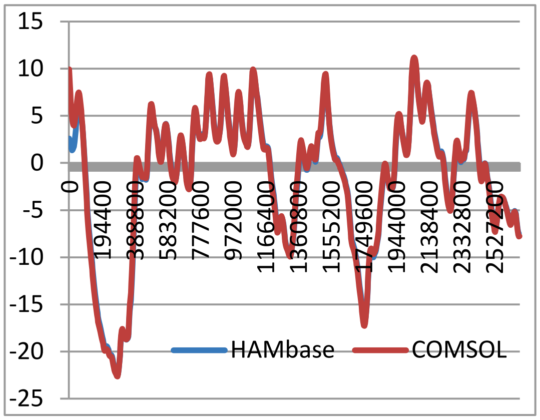

Figure 3 Interior temperatures over time as simulated in HAMBase and COMSOL, climate and facade

4.3 BESTEST climate, façade and volume

After changing the climate, the façade and increasing the volume from 0.98*0.98*0.98 m to 2.7*6*8 m in both the HAMBase model and the COMSOL model, both simulations were done.

Parameter	Simulated as in:
Climate	BESTEST
Façade	BESTEST
Volume	BESTEST
Ventilation	Annex 58
Heating and cooling	Annex 58
Windows	Annex 58

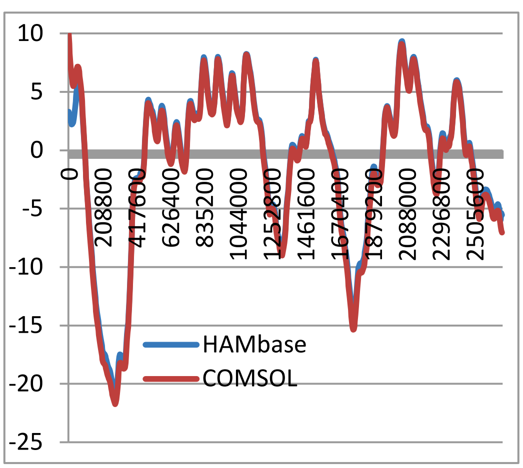

Figure 4 Interior temperatures over time as simulated in HAMBase and COMSOL, climate, façade and volume

4.4 BESTEST climate, façade, volume and ventilation

After changing the climate, façade, volume and adding ventilation using Equation 2 to simulate a situation with ACH = 0.5 and ACH=5 in the COMSOL model, both the HAMbase simulation and the COMSOL simulation were done.

Parameter	Simulated as in:
Climate	BESTEST
Façade	BESTEST
Volume	BESTEST
Ventilation	BESTEST
Heating and cooling	Annex 58
Windows	Annex 58

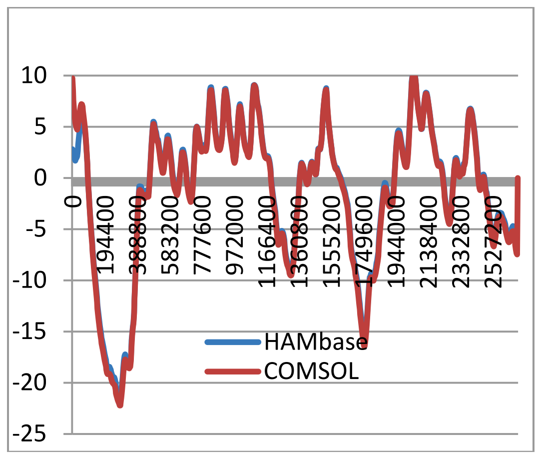

Figure 5 Interior temperatures over time as simulated in HAMBase and COMSOL, ACH=0.5

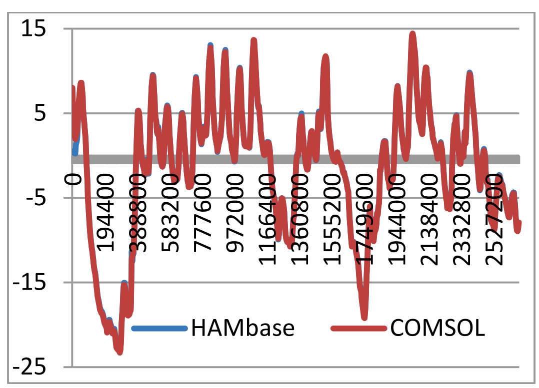

Figure 6 Interior temperatures over time as simulated in HAMBase and COMSOL, ACH=5

4.5 BESTEST climate, façade, volume, ventilation, heating and cooling

After changing the climate, façade, volume, ventilation and adding heating and cooling using Equation 3 and Equation 4 to simulate a situation with heating and cooling the COMSOL model, both the HAMBase simulation and the COMSOL simulation were done.

Parameter	Simulated as in:
Climate	BESTEST
Façade	BESTEST
Volume	BESTEST
Ventilation	BESTEST
Heating and cooling	BESTEST
Windows	Annex 58

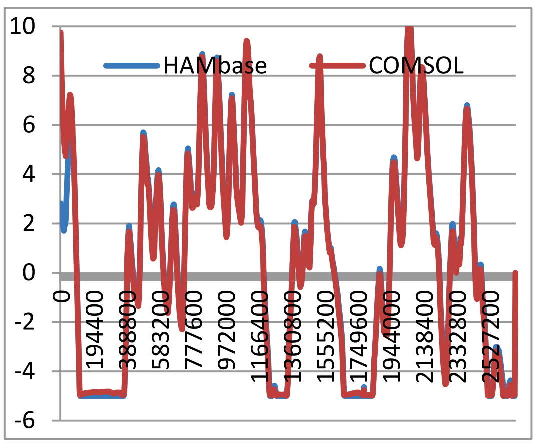

Figure 7 Interior temperatures over time as simulated in HAMBase and COMSOL

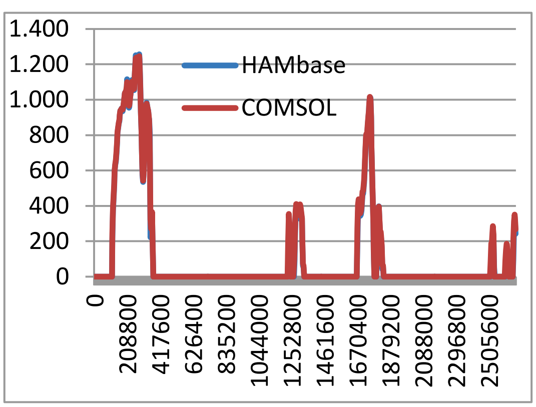

Figure 8 heating power over time as simulated in HAMBase and COMSOL

4.6 BESTEST climate, volume and windows

After changing the climate, volume and adding windows through the simplification as described in 'Windows' in the COMSOL model, both the HAMBase simulation and the COMSOL simulation were done.

Parameter	Simulated as in:
Climate	BESTEST
Façade	Annex 58
Volume	BESTEST
Ventilation	Annex 58
Heating and cooling	Annex 58
Windows	BESTEST

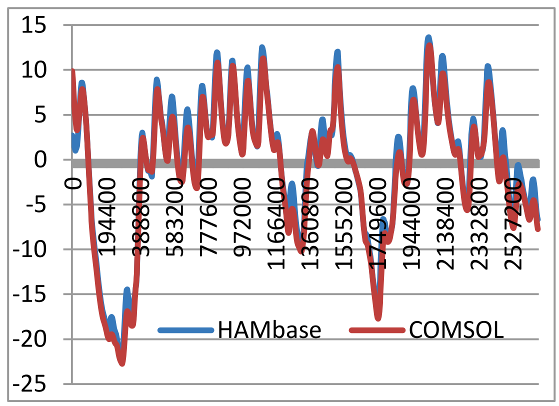

Figure 9 Interior temperatures over time as simulated in HAMBase and COMSOL

5. Conclusions

The results produced with the COMSOL model match the BESTEST results very well for every simulation. This means the COMSOL model is verified for the cases simulated in this research. The simulation with windows provides the biggest deviations but nevertheless it seems to accurate enough for energy performance simulations.

The main advantage of using COMSOL for energy performance, that it is 3 dimensional and graphical. This makes results accurate, easy to interpret and it provides visual insight into the thermal behaviour of the construction. A drawback to the new COMSOL model is the calculation time, although this is dependent on the computer that is used. The longest simulation time in this research was around 10,5 hours for a simulated period of 2 months. This could prove to long for certain applications.

The model provides the possibility of making a transient energy, thermal simulation simultaneously in 3 dimensions. Compared to most other BES Software programs, which are in 1D and 2D, respectively, this COMSOL model can provide more realistic results.

However, the model is not complete. Solar radiation must still be added to the model in order to get a complete whole building simulation. Second, it is important to find the exact cause of the differences between the HAMBase model and the COMSOL model for the simulation that includes windows, since it is not known at this point what causes these differences. Third, it might prove important to find a way of reducing the calculation time.

References

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