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ScienceDirect

Energy Procedia 132 (2017) 429–434

Energy Procedia

www.elsevier.com/locate/procedia

11th Nordic Symposium on Building Physics, NSB2017, 11-14 June 2017, Trondheim, Norway

Simulating the complete HAMSTAD benchmark using a single model implemented in Comsol

A.W.M. van Schijndel*, S. Goesten, H.L. Schellen

Eindhoven University of Technology, P.O. Box 513 5600MB Eindhoven, Netherlands

Abstract

Benchmarks are important tools to verify computational models. In the research area of building physics, the so-called HAMSTAD (Heat, Air and Moisture STAnDardization) project is a very well known benchmark for the testing of simulation tools. In contrast to earlier work where we used multiple (Comsol) models, in this paper we simulated all five subtasks of the benchmark by using a single model implemented in Multiphysics software Comsol 5.2a. We conclude that the single model provides satisfactory results on all parts of the benchmark and is therefore applicable for a wide range of HAM problems.

Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics.

Keywords: Heat, air, moisture, benchmark, Comsol

1. Introduction

Multiphysics tools for modeling heat and moisture transport in constructions, might encounter numerical problems. Especially the multi-layered mixed moisture transport (i.e. vapour and water) part can be tricky to solve.

In 2000, the European Union initiated the HAMSTAD (Heat, Air and Moisture STAndards Development) project on standardization procedures and certification in the field of heat, air, and moisture transport in building constructions [1,2]. In the total of five different benchmarks were developed. Amongst others van Schijndel [3,4] developed several models using Comsol to simulate parts of HAMSTAD benchmarks. Although the results were already satisfactory at that time, it did not contain all benchmarks so far. Moreover, for each benchmark a separate model was developed. With this paper, we revisit the HAMSTAD benchmarks using the latest version of Comsol (5.2a) and present a

* Corresponding author. Tel.: +31 40 247 29 57.
E-mail address: A.W.M.v.Schijndel@tue.nl

1876-6102
Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics
10.1016/j.egypro.2017.09.651

complete updated overview of all five benchmarks *for a single model.* The latter is the most important innovation. The main benefit is that this single model can be used for a wide range of HAM problems. Due to space limitations, only the most important results are included in this paper. We refer to HAMLab webpage [6], where all models and a detailed reports [5,7] are available.

2. The physics behind the model and implementation of the material properties and boundary functions

The heat and moisture transport can be described by the following PDEs using LPc as potential for moisture transfer.

$$C_T \frac{\partial T}{\partial t} = \nabla \cdot (K_{11} \nabla T + K_{12} \nabla LPc) \qquad (1)$$
$$C_{LPc} \frac{\partial LPc}{\partial t} = \nabla \cdot (K_{21} \nabla T + K_{22} \nabla LPc)$$

With:

$$\begin{aligned}
&LPc = {}^{10}\log(Pc) \\
&C_T = \rho \cdot c \\
&K_{11} = \lambda \\
&K_{12} = -l_{lv} \cdot \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT}, \\
&C_{LPc} = \frac{\partial w}{\partial Pc} \cdot \frac{\partial Pc}{\partial LPc} \\
&K_{22} = -K \cdot \frac{\partial Pc}{\partial LPc} - \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT}, \\
&K_{21} = \delta_p \cdot \phi \cdot \frac{\partial Psat}{\partial T},
\end{aligned} \qquad (2)$$

Where t is time [s]; T is temperature [^{o}C]; P_c is capillary pressure [Pa]; ρ is material density [kg/m^3]; c is specific heat capacity [J/kgK]; λ is thermal conductivity [W/mK]; l_{lv} is specific latent heat of evaporation [J/kg]; δ_p vapour permeability [s]; φ is relative humidity [-]; Psat is saturation pressure [Pa]; M_w = 0.018 [kg/mol]; R = 8.314 [J/molK]; ρ_a is air density [kg/m^3]; w is moisture content [kg/m^3];K is liquid water permeability [s]. The implementation of material and boundary functions was done by using MatLab. These functions are used to convert measurable material properties such as K, φ, δ_p and λ which are dependent on the moisture content into PDE coefficients which are dependent on the LPc and T. This is schematically shown in Figure 1 Left. For each material and at each point the vapour pressure can be calculated using similar corresponding functions.

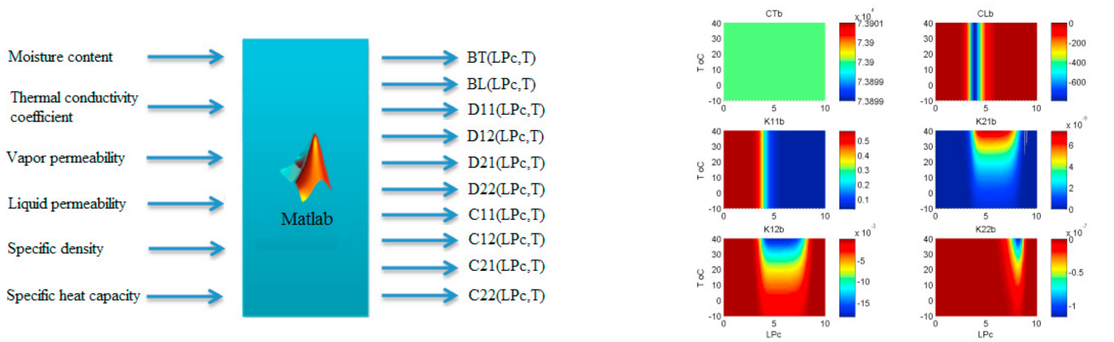

Fig. 1. Left: The conversion from measurable material properties into PDE coefficients. Rigth: PDE coefficients C_T, C_{LPc}, K_{ij} as functions of LPc and T calculated from the provided HAMSTAD benchmark no.1 material properties for insulation

3. Results of the Benchmarks Simulations

3.1. Benchmark No.1 Heat and moisture with condensation

A roof structure is analyzed in 1D regarding dynamic heat and moisture transport. The thermal insulation is facing the interior and there is a moisture barrier facing the exterior. The structure is perfectly airtight. Figure 2 Left shows the structure:

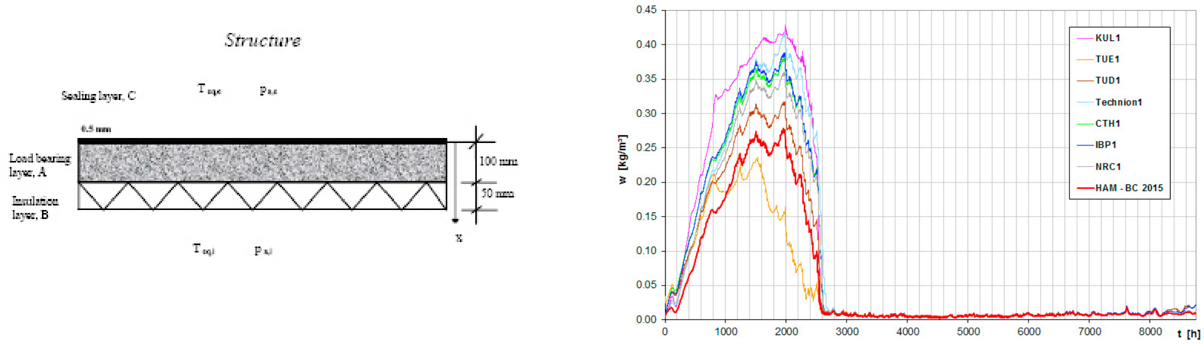

Fig. 2. Left: A schematic of the structure of benchmark 1. Right: The average moisture content in the insulation.

The most critical part is to simulate the amount of condensation in the insulation layer. Figure 2 Right shows the bandwidth of the benchmark result. The result of the COMSOL simulation is quite satisfactory.

3.2. Benchmark No. 2 Moisture (analytical solution)

The second HAMSTAD-benchmark is about an isotherm drying process of an initially wet 200 mm thick material. The initial conditions are 293 K and a relative humidity of 85%. The indoor boundary conditions are a temperature of 293 K and a relative humidity of 65%. The external side has the boundary conditions consisting of a temperature of 293 K and a relative humidity of 45%. For this benchmark an analytical solution is given. The model in COMSOL consists of a 1D-geometry, see Figure 3 Left

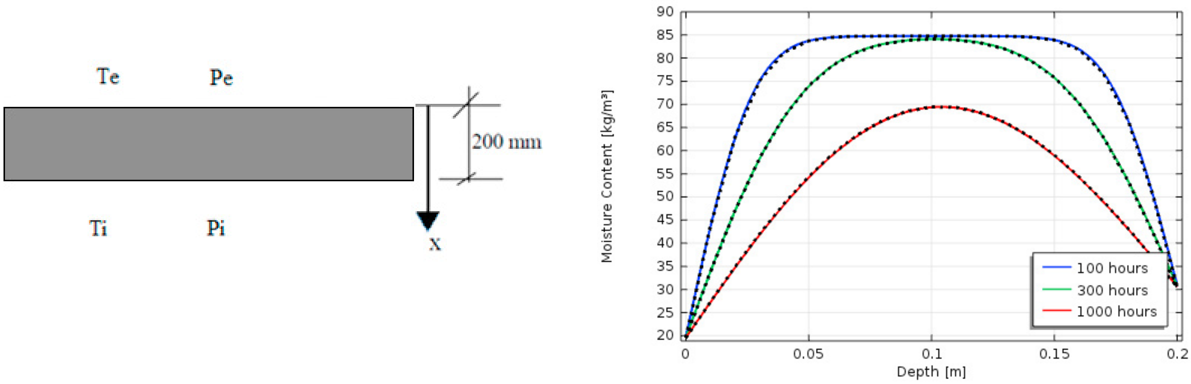

Fig. 3.Left: The geometry of benchmark 2 and Right: Moisture content [kg/m^3] related to the depth [m] measured from the outside after 100 hours, 300 hours and 1000 hours, where the colored graphs are the results of our model and the dotted graphs are the analytical solutions.

The results of Comsol are shown in Figure 3 Right, which depicts the moisture content [kg/m^3] across the thickness at 100 hours, 300 hours and 1000 hours. Comsol generates the same results as the analytical solution within the numerical accuracy.

3.3. Benchmark No. 3 Heat, Air and Moisture

Convective heat and moisture transport is simulated with HAMSTAD-benchmark 3 by inter-computer-model-comparison. A single-plane lightweight construction with a thickness of 200 mm is simulated, see Figure 4(a). The boundary conditions are constant, with the exception of the pressure difference between indoor and outdoor. First there is infiltration of air, caused by a pressure difference of 30 Pa, which at day 20 will be changed linearly to -30 Pa, which value is reached at day 21, *i.e.* to an exfiltration by an air pressure difference of 30 Pa, see Figure 4(b).

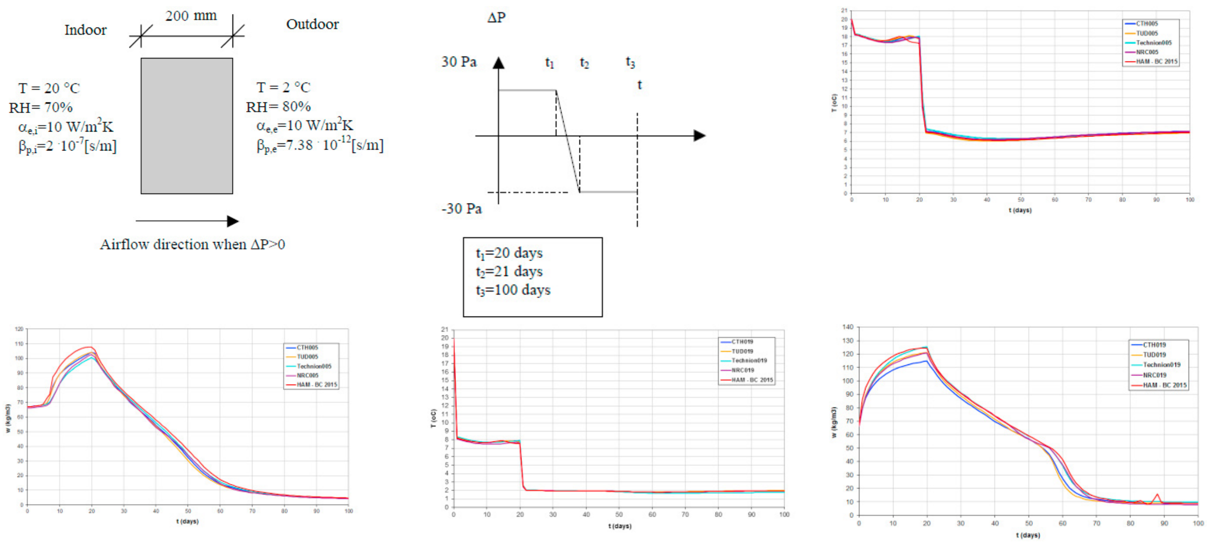

Fig. 4. (a) Geometry of the construction of benchmark 3; (b) the air pressure difference; (c) Temperature [°C] related to time [days] at 0.05 m (d) Moisture content [kg/m^3] related to time [days] at 0.05 m; (e) Temperature [°C] related to time [days] at 0.19 m.; (f) Moisture content [kg/m^3] related to time [days] at 0.19 m

For this benchmark we used smaller steps of temperature and logarithmic capillary pressure for the tables of the coefficients generated with MatLab. In Benchmark 1 we used steps of 0.2 Pa for LPc and 1°C for temperature, while here we used 0.01 Pa and 0.05°C. The data for creating the graphs have a time step of 24 hours. The results given in this paper are made with the convection method presented in Goesten [5]. Figure 4(c) shows the temperatures near the inner surface. The results of our model are in red. Figure 4(d) presents the moisture content near the inner surface. The moisture content increases at the start with the exfiltration (ΔP = +30 Pa), because the indoor air with the higher absolute humidity in the value of vapor pressure reaches the colder area near the outdoor environment. Both the temperature and moisture content decreases rapidly when the exfiltration (ΔP = +30 Pa) alters to infiltration (ΔP = -30 Pa), which is caused by the fact that the cold and dry air from the outside transports through the construction. It is visible in Figure 4(d) that our Comsol model simulates slightly larger moisture content values between day 8 and day 21 than the other models. Figures 4(e) and 4(f) show similar results but now near the outer surface. In Figure 4(e), the temperature decreases rapidly after the start of the simulation, which is caused by the fact that at the start of the simulation there is a sudden implementation of an air pressure difference of 30 Pa, while there is no initial air pressure difference. So the air pressure difference changes from 0 Pa to 30 Pa in an instant. From Figure 4(f), at the depth of 0.19 m, there is a little peak at the moisture content between 85 and 90 days, which is caused by the fact that the simulation uses a time step of 24 hours. This deviation does not occur when the time step is set on 1 hour. The description of benchmark 3 instructed the use of a 24 hour time step.

3.4. Benchmark No. 4 Heat and moisture with rain and sun

The geometry of benchmark 4 consists of a wall with a plaster at the inside, which is submitted to rain and a high temperature caused by solar irradiation (see Figure 5(a)). The structure is airtight; and therefore, no convective heat and moisture transport occurs.. The calculation time is 120 days.

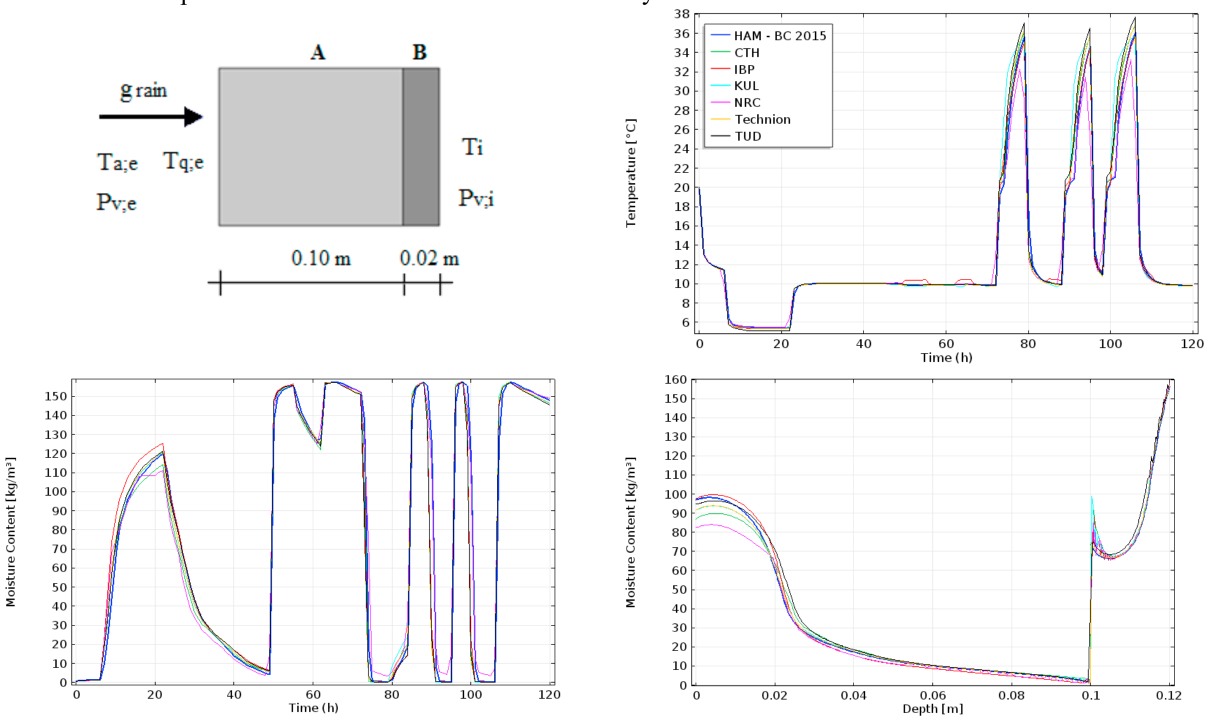

Fig 5. (a) Geometry and boundary conditions of HAMSTAD-benchmark 4; (b) Temperature [°C] related to time [hours] at the external surface; (c) Moisture content [kg/m^3] related to time [hours] at the external surface; (d) Moisture content [kg/m^3] related to depth [m] on 24 hours.

The temperature at the external surface of the construction is shown in Figure 5(b). This shows our model generates similar results as the other models for external surface temperature including the influence of rain and solar irradiation. The sudden increase of the temperature is caused by the solar irradiation. The results of Comsol are in blue. The moisture content at the external surface is shown in Figure 5(c), which shows that the influence of the rain flux on the moisture content at the external surface generated by our model leads to similar results as the other simulation models. Figure 5(d) depicts the moisture content over the depth of the construction at 24 hours, which shows that Comsol lead to similar results as the results of the different models from HAMSTAD. More results from HAMSTAD-benchmark 4 can be found in [5].

3.5. Benchmark No. 5 Moisture and layer interface

Benchmark 5 is about a wall with insulation applied at the internal side of the construction. The challenges in this benchmark are related to highly non linear material properties and the discontinuities at the interfaces between materials. Figure 6(a) shows the geometry. It consists at the outside of brick with a width of 365 mm, 15 mm mortar and 40 mm insulation material. The boundary conditions are constant and the results are from the last time step, *i.e.* 60 days. The results are the relative humidity and the moisture content of the last time step at 60 days.

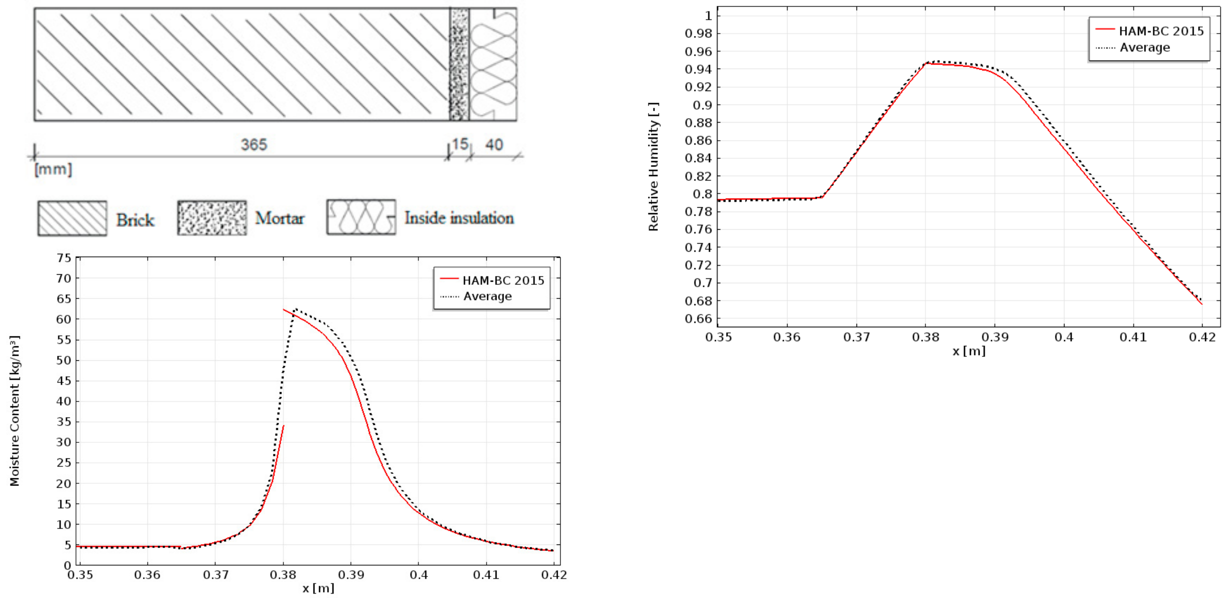

Fig. 6. (a) Geometry of the benchmark 5; (b) Relative humidity [-] related to the depth [m] on day 60. The result from HAM-BC 2015 is in red. The average results of HAMSTAD are depicted with the dotted line; (c) Moisture content [kg/m^3] related to the depth [m] on day 60. The result from HAM-BC 2015 is in red. The dotted line is the average result of HAMSTAD.

The results of Comsol are compared with the average values of benchmark 5 and presented in Figure 6(b) (relative humidity) and 6(c) (moisture content).In Figure 6(c) a discontinuity is visible due to the fact that each material has its own moisture retention curve.

4. Conclusions

In this paper we present the modeling and simulation of all five subtasks of the HAMSTAD benchmark using a single model implemented in Comsol 5.2a. We conclude that the Comsol model provides satisfactory results for the complete benchmark.

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