Moisture Risks in Multi-layered Walls - Comparison of COMSOL Multiphysics® and WUFI®PLUS Models with Experimental Results

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Abstract: Moisture can cause serious damages in different building components therefore the heat and moisture calculation in building constructions are important tasks. In the current paper, two different multi-layered walls, mainly consisted of wooden materials and mineral wool, are analyzed. Risks of mould growth under Latvian climate conditions are estimated using 3 different approaches: experimental results in real test houses, commercial software WUFI®PLUS for simultaneous heat and moisture transfer in 3D buildings and COMCOL for 1D case. Results obtained from this 3 approaches are compared. It is shown that calculations with COMSOL give good fitting with experimental results.

Keywords: moisture, mould growth, multi-layer wall.

1. Introduction

Directive 2010/31/EU of the European Parliament aims at promoting the energy performance of buildings and building units [1]. By 31 December 2020, all the new buildings are to become the "nearly-zero energy consumption buildings". Therefore, a sustainability analysis is required for different building solutions. Moisture is important factor that can negatively influence building's sustainability and human health as well as the energy efficiency of the house and environment, therefore the analysis of moisture risks and mould growth are required.

To achieve the goal, two test stands of houses, mainly consisted of wooden materials and mineral wool, was built in Riga, Latvia (see [2] for more information). These test stands can help to analyze moisture risks in a multi-layered wall under real Latvian climate conditions.

Nevertheless, numerical simulations of heat and moisture transfer through the multi-layered wall are also important tasks for complete analyze of building sustainability. Software WUFI, developed at the Fraunhofer institute [3], is classical program for calculating coupled heat and moisture transfer in building components. However, WUFI is commercial software that can be only used in the area of building physics. Moreover, it is not allowed to change some specific calculation parameters built in WUFI, e.g. boundary conditions are coupled. Therefore mathematical model of coupled heat and moisture transfer through building is implemented in COMSOL Multiphysics to compare results with those obtained with WUFI®PLUS simulations and experimental measurements.

2. Experimental measurements

Figure 1. Test stands of houses.

Five tests stands was built for the first time in Riga, Latvia (see Fig. 1). In the current paper, two of them are analyzed.

Table 1: Description of building construction walls

Test stands	**d** **m**	**λ** **W/(m·K)**	**μ** **[-]**
Stand of plywood panels			
Outside			
Plywood	0.02	0.17	700
Mineral wool	0.2	0.036	1
Plywood	0.02	0.17	700
Fibrolite	0.075	0.068	2
Lime plaster	0.015	0.7	7
Stand of wooden logs			
Outside			
Wooden logs	0.2	0.13	130
Mineral wool	0.2	0.036	1
Wooden log	0.04	0.13	130

In Table 1, short description of multi-layered walls, used in the test polygon, is given. Ventilated facades are created to protect exterior walls from the rain, solar radiation and wind therefore only outside temperature and relative humidity on the external wall can significantly influence moisture risks in a construction. More information about test stands and parameters of multi-layered walls is available in [2] and [4].

It is expected that the highest moisture risks is in the interlayer between the mineral wool and the plywood outside and in the interlayer between the outside wooden logs and mineral wool for the test stands of plywood and wooden logs, respectively (see Table 1).

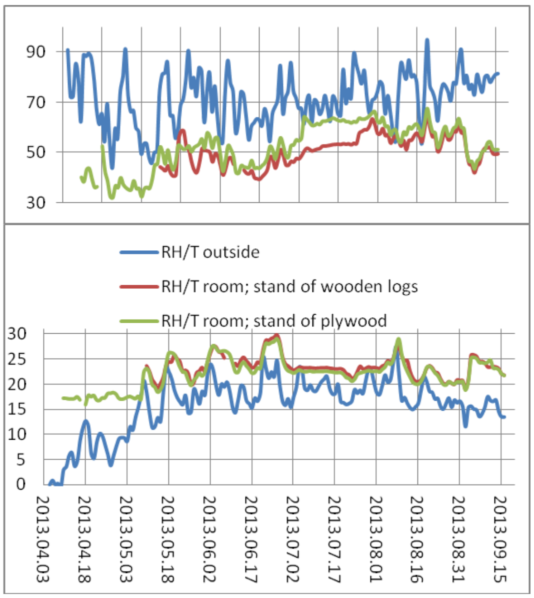


Figure 2. Measured daily average relative humidity and temperature.

Test stands of houses were built in December, 2012. Experimental results have been obtained from April, 2013. Controlled temperature at least +18°C was ensured till May 8. Then indoor temperature was not controlled. In July, cooling was ensured if indoor temperature was rise till 24°C. In August, windows were covered from outside to protect the room from solar influence. From September 3, heating has been applied to ensure indoor temperature from 21-26 °C. Indoor relative humidity has been fluctuated for free floating conditions all the time period. In Fig. 2, daily average relative humidity and temperature at the exterior and interior air are shown.

3. Simulation of Heat and Moisture Transfer in a Multi-layered Walls with WUFI®PLUS

WUFI®PLUS is 3D room climate model which can calculate indoor relative humidity and temperature taking into account outdoor climate conditions, air exchange, solar radiation through window etc. WUFI use model developed by Kunzel [3] for calculated coupled heat and moisture transfer through building components. WUFI®PLUS takes into account hourly outdoor climate values (in the current paper, solar radiation, relative humidity and temperature). WUFI®PLUS manual for detailed information is available in [5].

4. Governing Equations and use of COMSOL Multiphysics

For simultaneous heat and moisture transfer in the multi-layered wall, the following set of partial differential equations is used [2]:

$$\frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + h_v \frac{\partial}{\partial x}\left(\delta_p \frac{\partial\left(\varphi P_{sat}\right)}{\partial x}\right) = \rho_s\left(c_s + wc_w\right)\frac{\partial T}{\partial t} \qquad (1)$$

$$\frac{\partial}{\partial x}\left(D_\varphi \frac{\partial \varphi}{\partial x}\right) + \frac{\partial}{\partial x}\left(\delta_p \frac{\partial\left(\varphi P_{sat}\right)}{\partial x}\right) = \rho_s \frac{dw}{d\varphi}\frac{\partial \varphi}{\partial t}$$

Heat exchange and water vapour transfer on a surface is given by:

$$q = \alpha\left(T_{out} - T_{surf}\right)$$
$$g_v = \beta_p\left(p_{air} - p_{surf}\right) \qquad (2)$$

where $\alpha = \alpha_c + \alpha_r$, $\beta = 7 \times 10^{-9}\alpha_c$. Since solar radiation on exterior surface is negligible because of ventilated façade protected the walls, we assume $\alpha_r = 0$.

The temperature dependence of the saturation vapour pressure can be described as

$$P_{sat} = 611\exp\left(\frac{17.08T}{234.18+T}\right), \quad T \geq 0$$
$$P_{sat} = 611\exp\left(\frac{22.44T}{272.44+T}\right), \quad T < 0$$

Water vapour permeability for building material is given by:

$$\delta_p = \frac{\delta}{\mu}$$

with

$$\delta = 2\times10^{-7}(T-273.15)^{0.81}/P_L.$$

Liquid conduction coefficient can be described with:

$$D_\varphi = D_w\frac{dw}{d\varphi}.$$

For implementing the set of equations (1) with boundary conditions (2) in COMSOL Multiphysics, PDE interface is used. Governing equations (1), are overwrite into matrix notation:

$$\begin{pmatrix} a11 & a12 \\ a21 & a22 \end{pmatrix}\begin{pmatrix} \nabla^2 T \\ \nabla^2 \varphi \end{pmatrix} = \begin{pmatrix} b11 & b12 \\ b21 & b22 \end{pmatrix}\begin{pmatrix} \frac{\partial T}{\partial t} \\ \frac{\partial \varphi}{\partial t} \end{pmatrix} \quad (3)$$

In [6], it is explained in details how to implement the set of equation system (1) in COMSOL Multiphysics. In [7], similar COMSOL model verification was done.

5. Results and Discussions

We will focus on the moisture risks in critical places on the multi-layered walls: an interlayer between the mineral wool and the plywood outside and an interlayer between the outside wooden logs and mineral wool for the test stands of plywood and wooden logs, respectively (see Table 1).

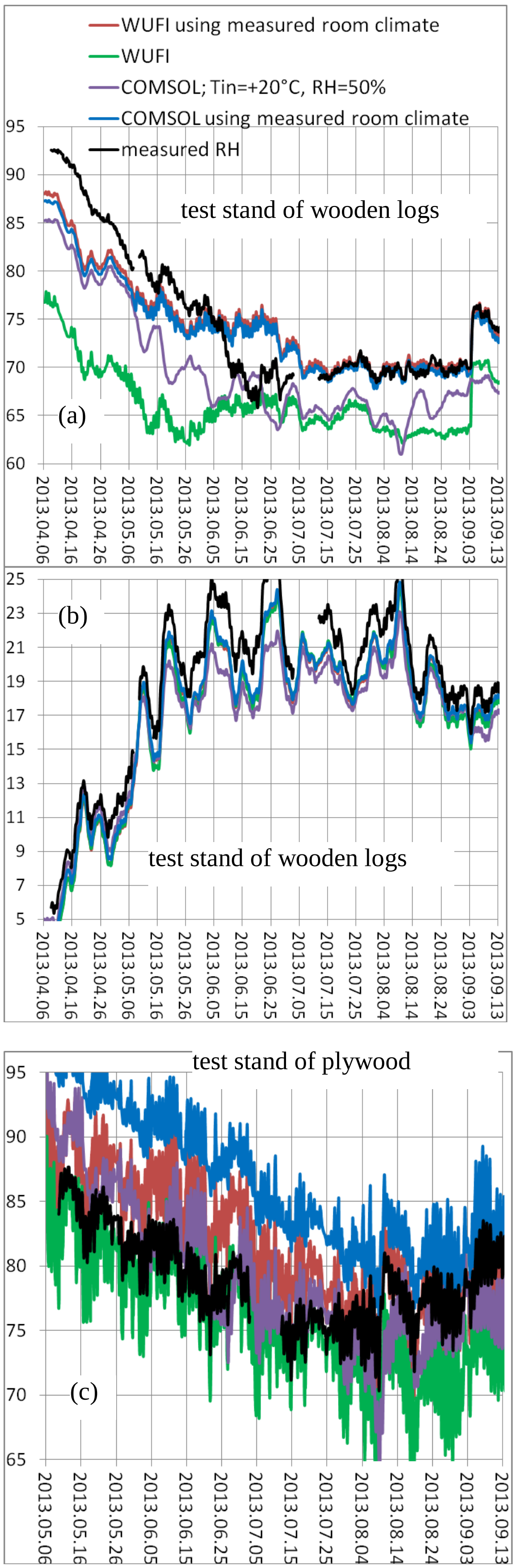
In COMSOL and WUFI we have implemented T_{out} and outdoor relative humidity at 1 h time step. For calculating indoor climate (that strongly influence wall's conditions) we use 2 approaches in WUFI: measured indoor T and φ (see Fig. 2) and built-in WUFI model for simultaneous inner climate behaviour. Since we use 1D wall model in COMSOL Multiphysics, we take constant values $T_{in}=20$ °C and $\varphi_{in}=50$ % or measured values.

In Fig 3, we see the dynamics of relative humidity and temperature in a critical place for test stands of wooden logs and plywood. When both outdoor and indoor are used measured T and φ, numerical models with WUFI and COMSOL should be as close as possible to measured results, therefore blue (COMSOL), red (WUFI) and black (measured results) should covered in Fig. 3.

Measured φ (black line) differs from COMSOL (blue line) and WUFI (red line) results till July for the test stand of wooden logs, see Fig. 3a. It is explained with the fact that till July ventilated facade (thickness approximately 3 cm) was not ensured with air circulation as well as it was planned and therefore this 3 cm air layer works a little bit as added multi-layer. From July, both COMSOL and WUFI models are well fitted with experimental results in this case. WUFI model (green line) which use its own built-in model for calculating indoor climate is also well fitted with experimental measurements. Only the level of a relative humidity differs. However, COMSOL 1D model with fixed indoor climate (violet line in Fig. 3a) shows different fluctuations in a critical place in a wall for the test stand of wooden logs therefore this approach is not precisely in the current case.

Now let us analyze the dynamics of relative humidity in a critical place of the wall for the test stand of plywood (Fig. 3c, 3e). Since only a thin plywood (2 cm, see Table 1) is between outside and critical place which have been analyzed, relative humidity significantly fluctuates. Obtained relative humidity level using COMSOL model is higher than measured φ and WUFI result (blue line against black and red lines, respectively, see Fig. 3c, e). Since at initial time period high moisture load was occurred in the test stand of plywood, it means that COMSOL approach do not works as well in that case when high moisture risks are observed.

At the same time, COMSOL approach using fixed T_{in}, φ_{in} shows good fitting with experimental results (Fig. 3e, violet line against black line). From this it can be concluded that T_{in}, φ_{in} fluctuations do not significantly influence condensate and mould growth risks in a given multi-layered wall (Table 1, stand of plywood).



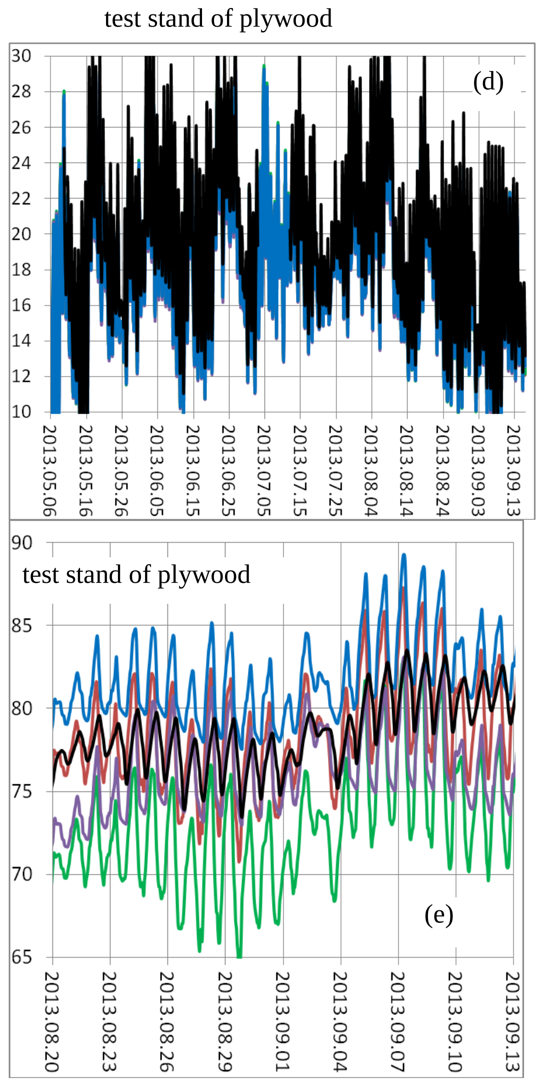


Figure 3. Dynamics of: (a), (c), (e) relative humidity; (b), (d) temperature in a specific place in a building construction. (a), (b); Interlayer between external wooden log and mineral wool for the test stand of wooden logs; (c), (d), (e) Interlayer between external plywood and mineral wool for the test stand of plywood.

It can be also observed that measured *φ* (black line in Fig. 3e) fluctuates with a smaller amplitude than *φ* that is obtained from numerical calculations. It is explained by the placement of humidity sensor for the test stand of plywood. It is possible that the sensor is not exactly in the interlayer adjacent to external plywood but a little bit deeper (1 cm from external plywood) in a construction in the direction towards the inside.

Since mould growth risks also depends on the temperature, an analyze of *T* in a critical place in a building constructions is also important task. In Fig. 3b it is shown that *T* is relatively low in April, when higher *φ* was observed (Fig. 3a). From this it can be concluded that mould growth risks are not so high in a test stand of wooden logs. In Fig. 3b it is shown that COMSOL (blue line) and WUFI (red line) approaches show the same result. However, slight deviations between numerical and measured results occurs. In Fig. 3d, we can see that dynamics of *T* in a critical place for the test stand of plywood are the same for all approaches used in a current paper. It can be explained by fact that external plywood does not helps significantly damp a critical place from outside temperature fluctuations.

6. Conclusions

The current paper demonstrates the differences between numerical simulations in WUFI plus and COMSOL Multiphysics with experimental results for 2 different multi-layered walls. It is shown that simple 1D model, implemented in COMSOL Multiphysics, shows good fitting with the experimental measurements for one multi-layered wall. However, significantly difference was observed for the second wall when high moisture risks was observed. From this it can be concluded that COMSOL Multyphysics works well for estimating mould growth risks in a multi-layered building constructions. However, if high risks of condensate formation in a construction could also occurs, WUFI PLUS shows better results in a comparison with measured results.

Since experimental results was obtained when building units had just been built, interesting challenge would be compare experimental results with thus obtained by WUFI®PLUS and COMSOL Multiphysics for a longer time period. Further task could also be implementing 3D model in COMSOL Multiphysics.

Nomenclature:

c_s	[J/(kg·K)]	Specific heat capacity of dry building material
c_w	[J/(kg·K)]	Specific heat capacity of water
d	[m]	Layer thickness
D_w	[m^2/s]	Liquid transport coefficient
$D_φ$	[kg/(m·s)]	Diffusion coefficient of liquid phase
g_v	[kg/m^2s]	Vapour diffusion flux density
h_v	[J/kg]	Heat of vaporization
P_L	[Pa]	Ambient atmospheric pressure
P_{sat}	[Pa]	Saturation vapour pressure
q	[W/m^2]	Heat flux density
T	[°C]	Temperature, °C;
t	[s]	Time
w	[kg/kg]	Dry basis moisture content
x	[m]	Wall thickness
α	[W/(m^2K)]	Total heat transfer coefficient
$α_c$	[W/(m^2K)]	Convective heat transfer coefficent
$α_r$	[W/(m^2K)]	Radiation-related heat transfer coefficient
$β_p$	[kg/(m^2sPa)]	Water vapour transfer coefficient
δ	[kg/(m·s·Pa)]	Water vapour permeability of air
$δ_p$	[kg/(m·s·Pa)]	Water vapour permeability of a material
λ	[W/(m·K)]	Thermal conductivity of a building material
$ρ_s$	[kg/m^3]	Bulk density of a dry building material
φ	[-]	Relative humidity

7. References

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