

Comparing TRNSYS and WUFI® plus simulation models- illustrated on models validated on measurements at Schack- Gallery Munich

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Keywords: TRNSYS, Wufi plus, simulation, moisture, temperatures, validation

ABSTRACT

The paper shows the validation of a simulation model created out of a part of a museal building against measured data, as a beginning. Thereafter the different approach in answering the questions of planning within the process of refurbishment in both systems will be outlined. This is done by showing the differences of the computation and their effect on the calculations. For example, in TRNSYS it is possible to use a detailed radiation model, using 3D modeling information, whereas in WUFI® plus only a GEOSURF-Factor can be used for radiation calculations. Comparing results from both simulations show differences in, for example temperature levels. Besides these differences and their effects on the simulation output, the paper finishes with the decision with which System the evaluation of further measurements of refurbishment can be performed best in this particular project.

1. Introduction

As part of the research consortium “Sustainable Refurbishment of Museum Buildings” extensive measurements were performed prior to the refurbishment of the Collection Schack in Munich. These measurements were used for creating and validating a building model in order to evaluate further measurements of refurbishment. The resulting model was implemented into the systems of TRNSYS and WUFI® plus in order to support the refurbishment furthermore.

The Institute for Building Physics of the Technische Universität München thereby was commissioned to analyse the most effective and cost-efficient method of refurbishment through these simulations. According to (Künzel 2006) one method in achieving this goal is using a coupled hygrothermal and energetic building simulation tool such as WUFI® plus. The context of this analysis gave the possibility of a comparison of two different simulation tools used during the analysing process with regards to the question whether in this special case a coupled hygrothermal and energetic building simulation leads to more effective and cost-efficient refurbishments.

2. The Schack Collection

Erected in 1909, the Schack collection house (fig. 1) is one of the most important collections of 19th-century German painting, founded by Adolf Friedrich von Schack (1815–1894). Suffering minimal damage during WW2, the building largely remains in its original state. Yet today, only two of the three existing floors (ground floor and 1st floor) are used as exhibition space. However, the collections owner, the Bavarian State Picture Collections, wishes to reactivate the vacant 2nd floor attic galleries. Therefore a redesign of the fire escape routes became necessary, itself resulting in an overall refurbishment of the 2nd floor and roofing areas. This enabled the responsible building authorities to take in a more holistic approach by participating in a national research programme.



Fig 1: Painting of collection Schack at about 1900

3. Model and Simulation tools description

3.1 Simulation model

The focus of refurbishment activities was located within the gallery rooms of the second floor (fig. 2 / 3). Since all other rooms are still used as exhibition space and all activities of refurbishment are limited to the gallery rooms, only this section of the second floor was modelled. All adjacent areas, like the first floor, the so called “Feuerbachsaal” to the north and others, are simulated as adiabatic borders. Only the staircase dominating the roof of the second floor was modelled as a shadowing device (purple area within fig. 4).

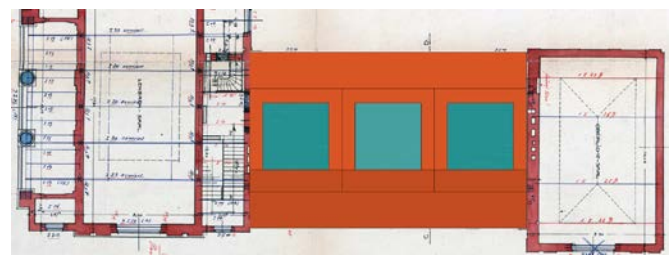


Fig 2: Floor plan of second floor of collection Schack with simulated area marked red and turquoise (top side orientated west)

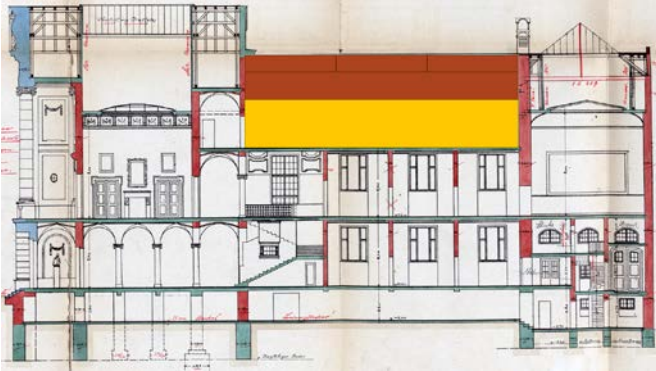


Fig 3: Longitudinal section of collection Schack with simulated area marked red and yellow

The modelled section within the second floor is divided into the three gallery rooms, with attics (fig. 4). Additionally, there are rooms covering the whole east and west sides of the galleries, in which radiators at the exterior walls are installed as the only heating system. The construction for the exterior and interior walls, floors and the roof is listed at table 1, 2, 3 and 4.

Table 1 Construction and resulting U-value of exterior walls

Layer	Material	Thickness [mm]	λ [W/mK]
1	interior rendering	15	0,70
2	solid brick	450/600/1000	0,81
3	exterior rendering	20	1,00
U_{exterior wall} =		1,3/1,1/0,69	[W/(m²K)]

Solar radiation enters the gallery room through the skylights of the roof sections and the semi-transparent dust cover. The parameters of the used windows are those of a single pane glazing with $U_g = 5,0$ W/(m²K) and SHGC of 0,85.

Table 2 Construction and resulting U-value interior walls

Layer	Material	Thickness [mm]	λ [W/mK]
1	interior rendering	15	0,70
2a	honeycomb brick	115	0,50
2b	concrete blocks	150	2,10
2c	solid brick	300/450/900	0,81
3	interior rendering	15	0,70
U_{interior wall a} =		1,9	[W/(m²K)]
U_{interior wall b} =		2,7	
U_{interior wall c} =		1,5/1,2/0,71	

The used weather data is obtained from the nearby weather station at the “Deutsches Museum” approx. 1 km away.

The heating system, in the eastern and western rooms, is controlled by a set point temperature of 21.5 °C for all 4 radiators. Additionally to the heating system a humidification with a set point of 40 % rel. humidity is installed in the adjacent eastern and western room also. Mechanical ventilation is not installed, but from the western room there are air channels to the gallery rooms and from the eastern room air channels lead to the attics, so a kind of natural driven ventilation through the rooms is possible. These air changes were simulated in a kind of pre-processing with natural ventilation calculated by using a formula of buoyant force. The results then were implemented into the final model.

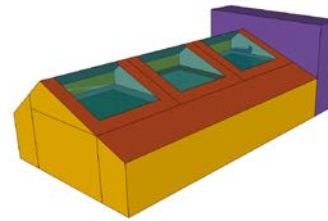


Fig 4: 3D drawing of the final simulation model with towering staircase as shadow device

Table 3 Construction and resulting U-value of floor slabs

Layer	Material	Thickness [mm]	λ [W/mK]
1*	parquet flooring, structural solid timber	30	0,13
2	cement screed	50	1,40
3	solid brick	200	0,81
4	interior rendering	15	0,70
U_{floor} =		1,1	[W/(m²K)]
U_{top floor} =		1,4	

* not on top floor

Table 4 Construction and resulting U-value of unisolated steep roof

Layer	Material	Thickness [mm]	λ [W/mK]
1	roof tiles	---	---
2	timber planking	30	0,130
3	timber rafter 8/14, e=60	---	---
U_{steep roof} =		2,5	[W/(m²K)]

3.2 TRNSYS 17

TRNSYS is a modular transient systems simulation program developed by the University of Wisconsin, Madison. It is primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design (Wikipedia 2011). The corresponding TRNSYS library consists of components (“types”), which can be assembled to form a system, for example a building exposed to the weather in Munich, including the overhead lights, some air exchange between rooms, and the heating system used in this building. Also it is possible to activate a buffer storage model which takes into account the humidity storage capacities of the surrounding elements.

3.3 Wufi®Plus

WUFI®plus is a room climate model which connects the energetic building simulation and the hygrothermal component calculation. With the building simulation software WUFI®plus the hygric and thermal ratios in a building, in its perimeter and their interaction can be calculated and quantified as well as the energy demand and consumption of system engineering (Fraunhofer 2010). The program consists of a graphical user interface within which all inputs are made by clicking and typing, without filling in and connecting types. In contrast to TRNSYS the humidity model is calculated as a standard model, but can be switched off.

4. Validation of simulation against measured data

4.1 Measurement System

For the acquisition of the air-temperature, surface-

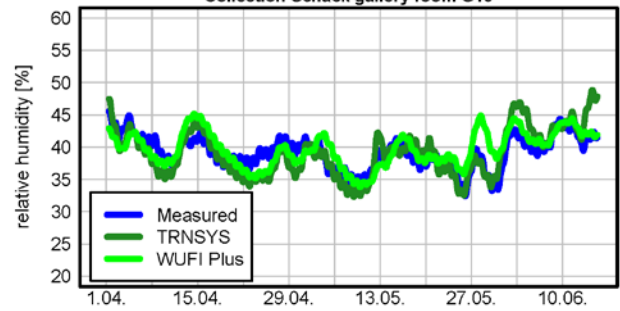


Fig. 7: Comparison of relative humidity in room 19 of collection Schack of measurement and simulation data

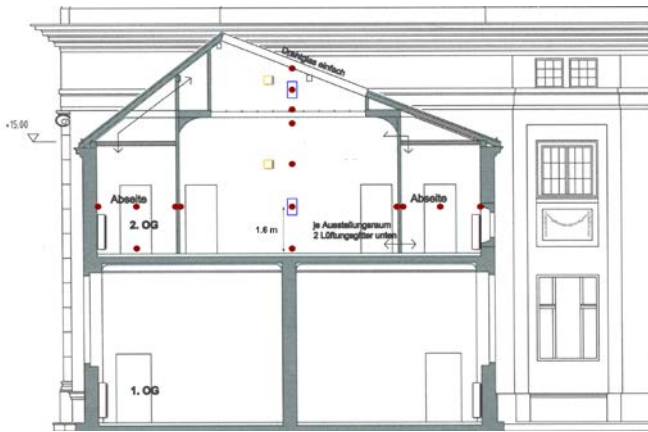


Fig. 5: Cross section of first and second floor of collection Schack with horizontal and vertical measurement axes

temperatures, heat-fluxes and relative humidity of the air a measurement-system based on Beckhoff-SPS-technology was set up. In the area of interest on the second floor three measurement axes were installed, one in north-south orientation over all three rooms, another one in east-west orientation in the middle of the centre room (fig. 5), and the third vertical axis also in this room for air temperature, relative humidity and heat flux through the dust cover and to the floor below (fig. 5). Additionally some data loggers from Onset Computer were used (“Hobos”), which save the acquired temperature and humidity data on a local memory and were read out regularly.

The corresponding outside-conditions were, as mentioned before, taken from a nearby weather station.

The measurement accuracy for the Hobos is ± 0.35 K for the temperature and typically ± 2.5 % for the relative humidity with a maximal uncertainty of ± 3.5 % (Hobo 2011).

The measurement accuracy for the Rotronic sensors used in the Beckhoff-system is given by ± 0.1 K for temperature and ± 0.8 % for relative humidity, with longtime stability smaller than 1 % per year, so for the sensors installed which were used for 3 years approximately ± 3.8 % accuracy for relative humidity (Rotronic 2011).

4.2 Validation results

In a first step the resulting temperatures of both programs, calculated with the moisture buffering method activated, were compared to the measurement data. The resulting graph is shown in fig. 6. The second step was then to compare the measured relative humidity with the one calculated (fig. 7).

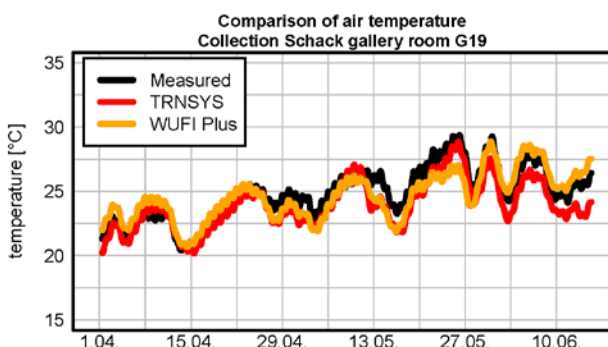


Fig. 6: Comparison of inner air temperature in room 19 of collection Schack of measurement and simulation data

The differences found between measurement and both simulation results have their source mainly within the difficulty to model the correct air change between the modelled zones, caused by the air channels between the rooms. This problem was addressed by calculating the air change in a pre-processing as shortly described before.

The standard deviation and mean values found between measurement and simulation within the final models can be seen in table 5 and 6. It is clear that all values are quite similar and within the range of errors obtained from the measurement results. The models therefore can be seen as validated against the measured data.

Table 5 Standard deviation and mean value of differences between measured data and simulation calculated with humidity model for TRNSYS

	standard deviation	mean value
for temperature	1.196 K	0.876 K
for rel. humidity	3.075 %	0.101 %

Table 6 Standard deviation and mean value of differences between measured data and simulation calculated with humidity model for WUFI@plus

	standard deviation	mean value
for temperature	1.441 K	0.178 K
for rel. humidity	3.078 %	-0.434 %

5. Different approaches of both tools

5.1 Ventilation model

5.1.1 Possibilities within the TRNSYS ventilation model

In TRNSYS there are several possibilities to calculate air flows between zones, as there are self-defined formulas using the equation type, TRNFlow, coupling air flows through surfaces and interzonal ventilation.

The implemented ventilation model in TRNSYS is based on coupling air flows through surfaces with user given ventilation rates, which were approximated by a pre-processing using natural ventilation based on temperature differences, the area and the height difference of in- and outlets.

5.1.2 Ventilation model within WUFI[®] plus

The implemented ventilation model in WUFI[®] plus is based on user given ventilation rates with the possibility of variation over time.

Three models are available, a model for natural ventilation, mechanical ventilation including infiltration both with air from the outside and an interzonal ventilation with air from the inside. All models can be addressed simultaneously. The system also consists of the possibility to integrate a previous generated file with given air change rates for all described models.

A calculation of air flows is not possible. Only a balance over all in- and outflows within every room is calculated. Dependent on the previous setting the tool automatically aborts calculation or compensates the error resulting out of a misbalance.

5.2 Radiation model

5.2.1 Radiation model in TRNSYS

In TRNSYS two radiation models can be used, the first based on geosurf-factors which can be adjusted by the user. The second is based on view factor matrices for every surface, which are automatically calculated from the geometry of the underlying SketchUp-model.

The radiation model implemented in the simulation is based on geosurf-factors, which were set to the same values as in WUFI[®] plus.

5.2.2 Radiation model in WUFI[®] plus

The radiation model in WUFI[®] plus contains only the so called geosurf- factor method which distributes the incoming radiation according to factor on every surface. These factor are fixed within WUFI[®] plus.

5.3 Moisture behaviour

5.3.1 Effective Capacitance Humidity Model in TRNSYS

In this model, the buffer effect of adsorptive and desorptive materials are considered by an effective moisture capacitance which is defined as the product of the air mass and a moisture capacitance ratio:

$$M_{eff,i} = R \cdot M_{air,i} \quad (1)$$

where $M_{eff,i}$ is effective moisture capacitance in the airnode (kg), $M_{air,i}$ is the mass of air in the airnode (kg) and R is a multiplication factor, generally in the range 1 to 10 (-).

A moisture balance for any airnode results in the following differential equation:

$$M_{eff,i} \frac{d\omega_i}{dt} = \dot{m}_{inf,i} (\omega_a - \omega_i) + \sum_k^{nvent} \dot{m}_{v,k,i} (\omega_{v,k,i} - \omega_i) + \dot{W}_{g,i} + \sum_{i-j}^{nsurfaces} \dot{m}_{cplg,s} (\omega_j - \omega_i) \quad (2)$$

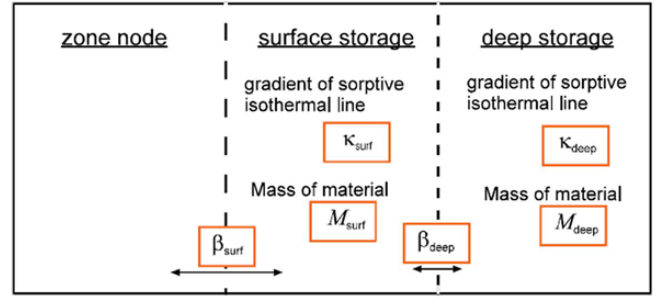


Fig. 8: Buffer storage humidity model of TRNSYS

where $M_{eff,i}$ is the effective moisture capacitance in the airnode (kg), ω_i is the humidity ratio of the airnode (-), ω_a is the ambient humidity ratio (-), $\omega_{v,k,i}$ is the humidity ratio of the ventilation air from ventilation type k (-), $\dot{W}_{g,i}$ are the internal moisture gains (kg/s), ω_j is the humidity ratio of an adjacent airnode j (-), $\dot{m}_{inf,i}$ is the air mass flow rate from infiltration (kg/s), $\dot{m}_{v,k,i}$ is the air mass flow rate from ventilation type k (kg/s), $\dot{m}_{cplg,s}$ is the air mass flow rate of air entering airnode i (kg/s).

This is described in detail in (TRNSYS 2010).

5.3.2 Buffer Storage Humidity Model in TRNSYS

This model describes a separate humidity buffer divided into a surface and deep storage. These are connected to each other as shown in fig. 8, the surface buffer is additionally connected with the air node.

In this model the moisture balance results in the following differential equations:

$$M_{air,i} \frac{d\omega_i}{dt} = \dot{m}_{inf,i} (\omega_a - \omega_i) + \sum_k^{nvent} \dot{m}_{v,k,i} (\omega_{v,k,i} - \omega_i) + \dot{W}_{g,i} + \sum_{i-j}^{nsurfaces} \dot{m}_{cplg,s} (\omega_j - \omega_i) + \beta_{surf} (\omega_{surf} - \omega_i) \quad (3)$$

$$M_{surf} \kappa_{surf} f(\varphi, \omega) \frac{d\omega_{surf}}{dt} = \beta_{surf} (\omega_i - \omega_{surf}) + \beta_{deep} (\omega_{deep} - \omega_{surf}) \quad (4)$$

$$M_{deep} \kappa_{deep} f(\varphi, \omega) \frac{d\omega_{deep}}{dt} = \beta_{deep} (\omega_{surf} - \omega_{deep}) \quad (5)$$

Where ω_{surf} is the humidity ratio of the surface storage (-), ω_{deep} is the humidity ratio of the deep storage (-), β_{surf} is the exchange coefficient between airnode and surface storage (-), β_{deep} is the exchange coefficient between surface storage and deep storage (-), κ_{surf} is the gradient of sorptive isothermal line of surface buffer (kg_{water}/kg_{material}/rel. humidity), κ_{deep} is the gradient of sorptive isothermal line of deep buffer (kg_{water}/kg_{material}/rel. humidity), $f(\varphi, \omega)$ the conversion factor from relative humidity to humidity ratio (-).

It is described in detail in (TRNSYS 2010).

5.3.3 Comparison of humidity models in TRNSYS

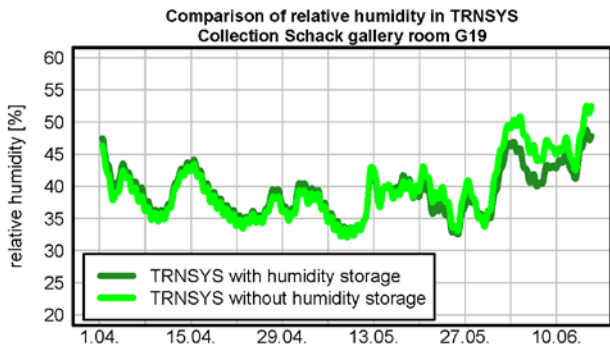


Fig. 9: Result of simulation with TRNSYS using and ignoring the humidity model

In figure 10 the relative humidity calculated in the two different TRNSYS humidity models are compared. As expected, the buffer effect in the buffer storage model leads to some slower change of humidity. But both models do not represent exactly the measured humidity development.

Table 7 : Standard deviation and mean value of differences between simulation with and without humidity model for TRNSYS

	standard deviation	mean value
for temperature	0 K	0 K
for rel. humidity	1.748 %	-0.478 %

5.3.4 Humidity model in WUFI[®]plus

The humidity model in WUFI[®]plus is the same as in the related program WUFI[®]pro, which is a simulation tool to calculate moisture problems in structures without a coupled thermal simulation.

$$\frac{\partial H}{\partial \theta} \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \left(\lambda \frac{\partial \theta}{\partial x} \right) + h_v \frac{\partial}{\partial x} \left(\frac{\delta \partial p}{\mu \partial x} \right) \quad \text{Heat transport}$$

$$\rho_w \frac{\partial u}{\partial \varphi} \frac{\partial \varphi}{\partial t} = \frac{\partial}{\partial x} \left(\rho_w D_w \frac{\partial u}{\partial \varphi} \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial x} \left(\frac{\delta \partial p}{\mu \partial x} \right) \quad \text{Moisture transport}$$

- D_w [m²/s] Liquid transport coefficient
- H [J/m³] Enthalpy of moist building material
- h_v [J/kg] Evaporation enthalpy of water
- p [Pa] Water vapor partial pressure
- u [m³/m³] Water content
- δ [kg/msPa] Water vapor diffusion coefficient in air
- θ [°C] Temperature
- λ [W/mK] Heat conductivity of moist material
- μ [-] Vapor diffusion resistance factor of dry material
- ρ_w [kg/m³] Density of water
- φ [-] Relative humidity

Fig. 10: Equations of heat and moisture transport implemented within WUFI[®]pro/plus (Künzel 1995)

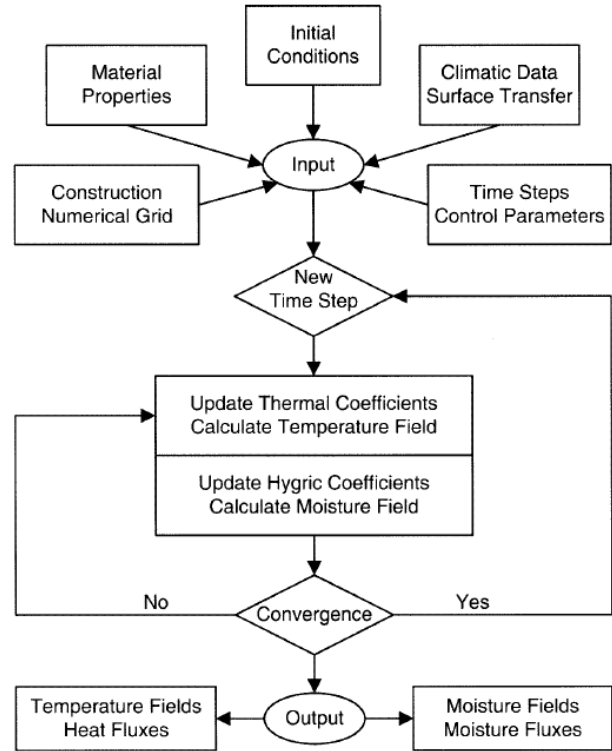


Fig. 11: Flow chart of the calculation technique of WUFI[®]pro (Künzel 1995)

The program WUFI[®]pro simultaneously solves equations related to heat and moisture transfer in a multi-layer building component using the equations shown in fig. 10. The flow chart of this calculation is shown in fig. 11. As climatic boundaries WUFI[®]pro uses realistic weather data for outside and generated data for inside conditions. As surface transfer conditions average values for the exterior and interior heat and vapour transfer coefficients are used.

WUFI[®]plus uses, as mentioned before, the same method of calculation for structures as described for WUFI[®]pro, with the extension of calculating the inner conditions, unlike using pre generated data. The main difference to TRNSYS is the calculation of heat and moisture transport through the whole multi-layer building component and the coupling of these processes with the parallel computed thermal conditions within the room model.

5.3.5 Comparison of result of calculation with an without humidity model in WUFI[®]plus

The comparison shows that the humidity model has only little but existing impact on inner air temperatures, whereas the impact on relative humidity is recognisable (table 4).

Due to the fact that multi-layer components are calculated the buffering and humidity transport through the boundary components diminishes the amplitude of relative humidity. The mean of the results calculated with the humidity lies with 0.0167 % underneath the mean result calculated without the humidity model. Comparing these results with the measured data also shows, that the results obtained with the humidity model are closer to the measured data results.

As a matter of fact a little influence is shown after switching from simulation with humidity model to one without according to the resulting temperatures. This influence

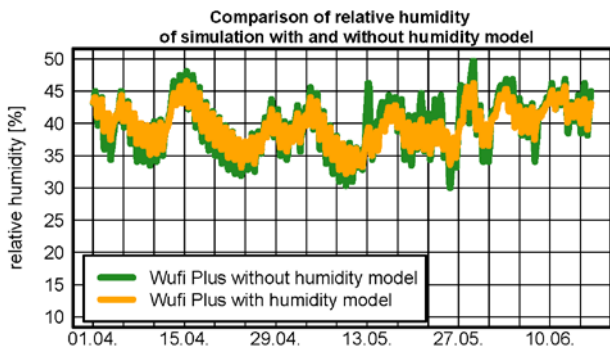


Fig. 12: Result of simulation with WUFI®plus using and ignoring the humidity model

indicates not only is the heat and moisture transport calculated through the multi-layer building component, but also over the boundary layer between the components surface and the air node within the room. Therefore the sensible and latent heat is balanced.

Table 8 : Standard deviation and mean value of differences between simulation with and without humidity model for WUFI®plus

	standard deviation	mean value
for temperature	0.150 K	-0.0058 K
for rel. humidity	-0.0167 %	1.521 %

6. Conclusion

The comparison led to the conclusion that regarding the achievable results both tools are likely to be used in this specific case. Also there are differences within the resulting values these distinctions are quite small. The range of the standard deviation for temperature is between approx. 1.4 K and 1.2 K. The range of the standard deviation according relative humidity is between approx. 4.2 % and 3.1 %.

Although there are differences within the calculation with and without humidity models, an influence on relative humidity of approx. 1% or more is seen only within the simulation of TRNSYS. After activation of the buffer storage model the standard deviation for relative humidity decreases. A significant influence on temperature behaviour of results of both tools calculated with the differences in modelling described cannot be obtained.

In this specific case the leading influence on both temperature and relative humidity is the air change rate, so the influence of modelling with or without humidity models is diminished. Taking into account that the calculation time increases by using the humidity model, for example a factor of approx. 2 is obtained within WUFI®plus, these models should only be used to calculate problems with low air changing rates.

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