

# The use of COMSOL for Building Constructions Engineering regarding Heat and Moisture Transport

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**Abstract:** Hunting Lodge St. Hubertus is one of the most prominent Dutch buildings from the early twentieth century. It is a preserved national monument of exceptional cultural and historical interest. This is why the Dutch Government Building Agency has expressed its concern about the observed moisture damage in the tower of the building. The main objective of this study was to map the causes of the moisture problems in the tower and to recommend possible solutions to repair the damage whilst preventing further deterioration. An extensive study of wind and wind-driven rain (WDR) was conducted to provide insight into the moisture load of the building facade, using measurements and CFD (Computational Fluid Dynamics) simulations. The following damage categories are distinguished: efflorescence, cracking, soiling, moist spots, mechanical damage and biological growth. It is concluded from this study that a connection exists between the rain load of the facades and the damage on the inside, since most damage is observed on the interior surface of the facade that is most subjected to WDR. It is concluded that the moisture problems are indirectly dependent on the WDR load. The rain penetrates to the interior at places of inadequate detailing and therefore causes damage mainly near openings in the facade and on the inside of the facade below balconies. It is of great importance to improve the detailing of the joints of the different building elements. Because of the difficulty to solve the problems concerning rain penetration nearby openings in the solid outer walls by improving the detailing of the frames whilst maintaining the authentic character of the facade, it is furthermore recommended to use a moisture-resistant restoration plaster in the tower that can withstand the crystallization of salts without causing damage. The COMSOL software was used for modeling the moisture transport through the walls of the tower.

**Keywords:** Driving rain, moisture problems, heat and moisture transport, measurement, simulations

## 1. Introduction

Hunting Lodge St. Hubertus is situated in the midst of the extensive natural reserves of the Dutch National Park De Hoge Veluwe (Figure 1). The Hunting Lodge was built between 1916 and 1922 by Holland's most well-known architect from that time: H.P. Berlage. It is one of the most prominent buildings from the beginning of the twentieth century and is noted in the top 100 list of Dutch monuments. The floor plan of the brick structure is characterized by the tower in the middle of the building with a height of over 30 meters and by the wings that stretch out diagonally. Hunting Lodge St. Hubertus is part of the Dutch cultural heritage and is state property.

The history of moisture related problems in the Hunting Lodge is quite long. Since the details of the building are very old and rather complicated for the time in which they were designed, the walls of the tower are solid brick and the fact that there is limited heating in the tower, one can expect that there will be some moisture problems in this historic building. The first severe moisture problems in the Hunting Lodge occurred only twenty years after the completion of the building, in the period 1942-1944.



**Figure 1.** Hunting Lodge St. Hubertus.

A layer of concrete that would slow down the moisture transfer through the construction has been applied on the inside of the walls in these

years, because of problems with rain penetration and condensation on the inner surface. The rain load of the southwest facade of the building has been measured and simulated by Briggen (2007) (Figure 5).

This paper comprehends the heat and moisture transport inside the walls of the tower. Figure 3 shows a cross-section of these walls, consisting of two materials: brick and concrete.

## 2. Inspection of the moisture damage

The damage on the inside of the tower, and where possible also on the outside, is systematically inspected. The location and type of each moisture problem are documented in a table, illustrated with a picture of the damage. The moisture problems that manifest themselves in the tower of the Hunting Lodge can be divided in the following categories: efflorescence, cracking, soiling, moist spots, mechanical damage and biological growth. A picture of the typical moisture damage that occurs in the tower is shown in Figure 2.



**Figure 2.** Moisture damage at the inside of the tower

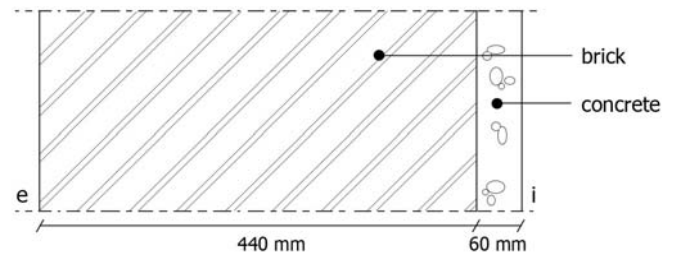
Regarding the location of the damage it can be concluded from the inspection that most damage occurs on the interior surface of the south-west facade of the tower. Since the prevailing wind direction in the Netherlands is south-west, which means that the south-west facade of the tower is subjected to wind-driven rain the most, there appears to be a connection between the rain load of the facade and the damage on the inside. There are no clear differences between the damage on lower or higher floors or between the

damage on the middle and on the sides of the facade. Most damage occurs near openings in the facade and on the interior surface of the facade below balconies.

The inspection of the damage enables a thorough assessment of the possible causes of the moisture problems. This assessment will be very useful for recommending solutions that repair the damage whilst further deterioration is prevented. Although an indication of the causes of the damage is already given by the inspection, it is very important to support these expectations by HAM simulations based on accurate WDR boundary conditions. An extensive wind, rain and wind-driven rain study was carried out to determine the WDR boundary conditions. This study consists of measurements and numerical simulations of WDR and is outlined in Briggen (2007).

## 4. Measurements

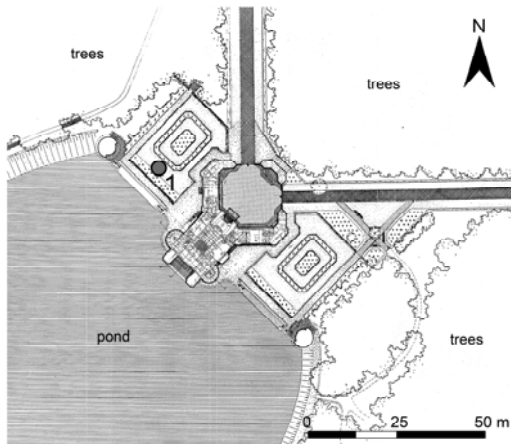
The data set is part of the measurement program at the Hunting Lodge St. Hubertus site, performed during 2006-2007 by Briggen (2007). Details of this project can be found there. One of problems seemed to be high moisture contents at the inside surface of the facade of the tower. The construction of this facade is shown in figure 3.



**Figure 3.** Horizontal section of the building facade

The outside climate conditions were measured by a weather station within 50m from the building. See figure 4.

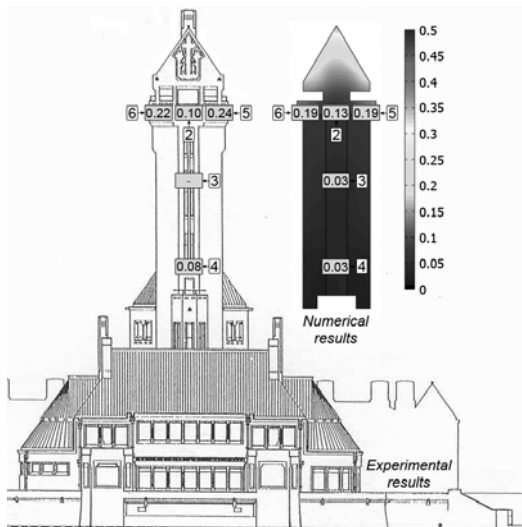
The inside air temperature and relative humidity were measured using standard equipment (see figure 6). A representation of inside surface conditions was obtained by placing a small box (5cm x 5cm x 1cm) against the wall and measure the air temperature and relative humidity inside. The estimation of the measurement error of this method is left over for future research.



**Figure 4.** Position of the meteorological mast (measurement of reference wind speed and reference wind direction) and the horizontal rain gauge, position 1.

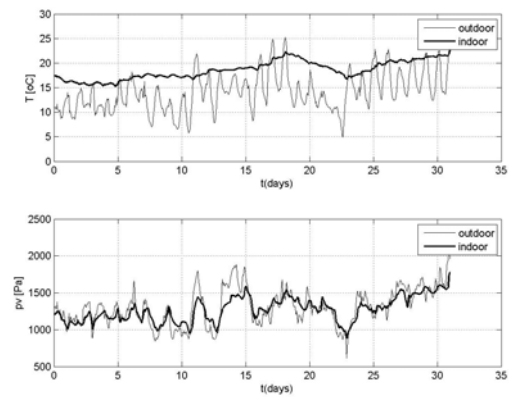


**Figure 6.** Measurement of the surface temperature and relative humidity at the inside surface of the tower, using a closed box, connected to the inside surface, supposed to be in equilibrium with the wall.

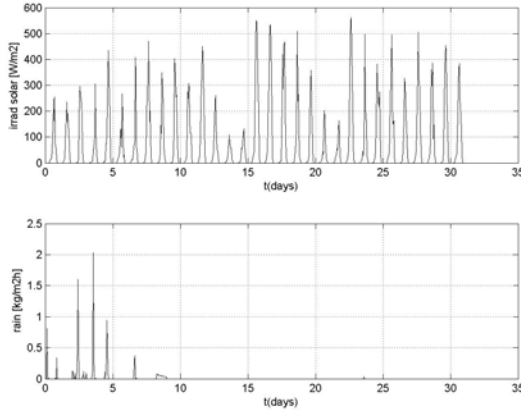


**Figure 5.** Spatial distribution of the catch ratio for the rain event of September 17<sup>th</sup>, 2007. The experimental results at the locations of the wind-driven rain gauges are shown on the left; the numerical results are shown on the right.

The *input* data consist of the measured time series of the indoor and outdoor climate as presented in figures 7 and 8.



**Figure 7.** The measured air temperatures (top) and calculated vapour pressures (bottom, from measured T/RH)



**Figure 8.** The measured solar irradiance (top) and rain intensity (bottom)

## 5. Modeling

As mentioned in Section 1, a comprehensive model capable of simulating the requested data is required. Amongst other possibilities, the multiphysics modeling approach of van Schijndel (2007) is selected. A guideline on how to implement up to 3D heat air and moisture (HAM) transport models using COMSOL (2008) is already provided (van Schijndel 2006). There are two major extensions to this work, described in the following sections: First, the implementation of LPc as moisture potential for including both vapour and liquid transport and second, the implementation of material and boundary functions for calculating the PDE coefficients from the material properties. The implementation of the two new extensions was verified using the HAMStad benchmark 1 (Hagentoft et al 2002).

### 5.1 Implementation of LPc potential

The heat and moisture transport in a solid can be described by the following governing PDEs:

$$C_T \frac{\partial T}{\partial t} = \nabla \cdot (K_{11} \nabla T + K_{12} \nabla LPc)$$

$$C_{LPc} \frac{\partial LPc}{\partial t} = \nabla \cdot (K_{21} \nabla T + K_{22} \nabla LPc)$$

$$LPc = {}^{10} \log(Pc)$$

With

$$C_T = \rho \cdot c$$

$$K_{11} = \lambda$$

$$K_{12} = -l_{lv} \cdot \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT},$$

$$C_{LPc} = \frac{\partial w}{\partial Pc} \cdot \frac{\partial Pc}{\partial LPc}$$

$$K_{21} = \delta_p \cdot \phi \cdot \frac{\partial Psat}{\partial T}$$

$$K_{22} = -K \cdot \frac{\partial Pc}{\partial LPc} - \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT},$$

Where t is time [s]; T is temperature [°C]; Pc is capillary pressure [Pa]; ρ is material density [kg/m³]; c is specific heat capacity [J/kgK]; λ is thermal conductivity [W/mK]; l<sub>lv</sub> is specific latent heat of evaporation [J/kg]; δ<sub>p</sub> vapour permeability [s]; φ is relative humidity [-]; Psat is saturation pressure [Pa]; M<sub>w</sub> = 0.018 [kg/mol]; R = 8.314 [J/molK]; ρ<sub>a</sub> is air density [kg/m³]; w is moisture content [kg/m³]; K is liquid water permeability [s].

The (i)nternal boundary conditions are:

$$q_i = \alpha_i \cdot (T_i(t) - T) \quad [W / m^2],$$

$$g_i = \beta_i \cdot (p_i(t) - p) \quad [kg / sm^2]$$

The (e)xternal boundary conditions are:

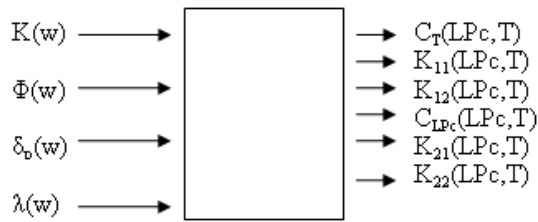
$$q_e = \alpha_e \cdot (T_e(t) - T) + q_{solar}(t) \quad [W / m^2],$$

$$g_e = \beta_e \cdot (p_e(t) - p) + g_{rain}(t) \quad [kg / sm^2]$$

### 5.2 Implementation of advanced material and boundary functions

The second extension is the implementation of advanced material and boundary functions using Matlab. These functions are used to convert measurable material properties such as K, φ, δ<sub>p</sub> 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 9.

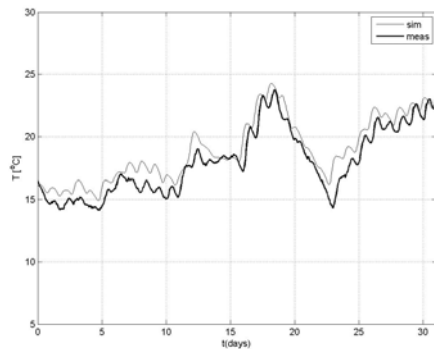


**Figure 9.** The conversion from measurable material properties into PDE coefficients

For each material and at each point the vapour pressure can be calculated using a similar corresponding function.

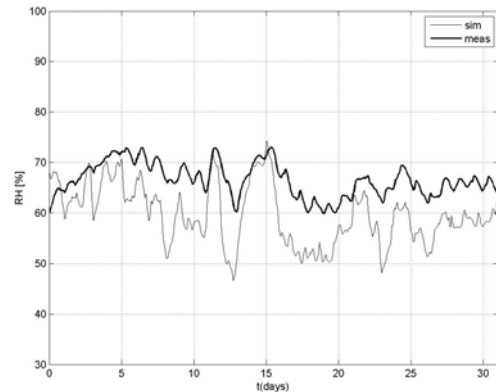
## 6. Results

The material database of DELPHIN (2008) is used to provide material properties. For brick, the Brick material properties of DELPHIN are used with constant  $\rho = 1700$ ;  $c = 840$ ;  $\lambda = 0.85$  and variable moisture properties using the tables. For concrete, the Lime plaster properties of DELPHIN ( $\rho = 1800$ ;  $c = 840$ ;  $\lambda = 1.05$ ) are used in the same way. From these data, the PDE coefficients were determined similar to figure 9 and together with the boundary conditions implemented using the COMSOL model of Section 5. Figure 10 and 11 show the results.



**Figure 10.** The measured and simulated inside surface temperature.

Figure 10 shows that the simulated inside surface temperature is already quite close to the measured one.



**Figure 11.** The measured and simulated relative humidity at the surface.

The simulated relative humidity at the inside surface of figure 11 seems to be less close to the measured one compared to the previous figure.

## 7. Conclusions

The provided COMSOL PDE model for simulating heat and moisture transport in constructions is validated with measurements. This model will be used to evaluate the long term durability of the current construction and alternative designs.

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