

Heat and Moisture Transport in a Semi-Infinite Wall

Introduction

This tutorial shows how to simulate coupled heat and moisture transport in a building component. The 1D model is a benchmark test defined in Norm EN 15026 for the validation of a software computing moisture transfer by numerical simulation. You can verify that the numerical results obtained with COMSOL Multiphysics are within the validity ranges specified in the norm. See Ref. 1 for details about the norm.

Model Definition

The model geometry consists of a single segment for the building component. Its size is taken large enough to represent it as a semi-infinite region for the simulation time-scale. A relative humidity of 50% and a temperature of 20°C are set as initial conditions, while on the left boundary the relative humidity is set to 95% and the temperature is 30°C.

The time-dependent study is run over one year, with a control of the temperature and relative humidity distributions at 7, 30, and 365 days.

MOISTURE TRANSPORT

The Moisture Transport in Building Materials interface is used to model the moisture storage and the moisture transport by vapor diffusion and capillary flow.

HEAT TRANSFER

The Heat Transfer in Building Materials interface computes the latent heat transfer due to vapor diffusion. In addition, moisture-dependent material properties are used to account for the effects of moisture content on thermal conduction and heat storage.

MATERIAL DATA

The hygroscopic and thermal material data needed in the equations solved by the Moisture Transport and Heat Transfer interfaces are defined in Norm EN 15026.

Hygroscopic Properties

The moisture storage function w (SI unit: kg/m³) is given by the following sorption isotherm:

$$w = \frac{146}{(1 + (-8 \times 10^{-8} \cdot R_{\rm H2O} T_{\rm ref} \rho_{\rm w} \ln(\phi))^{1.6})^{0.375}}$$

where ϕ (dimensionless) is the relative humidity, $R_{\text{H2O}} = 462 \text{ J/(kg·K)}$, $T_{\text{ref}} = 293.15 \text{ K}$, and $\rho_{\text{w}} = 1000 \text{ kg/m}^3$. The moisture diffusivity $D_{\rm w}$ (SI unit: m²/s), used for the expression of the liquid water flux, is defined as:

$$D_{\rm w} = -K \frac{\partial s}{\partial w}$$

where the suction stress s (SI unit: Pa) is defined as:

$$s = 0.125 \times 10^8 \left(\left(\frac{146}{w}\right)^{\frac{1}{0.375}} - 1 \right)^{0.625}$$

and the liquid water permeability K (SI unit: kg/(m·s·Pa)) is defined as:

$$K = \exp(-39.2619 + 0.0704 \cdot (w - 73) - 1.742 \times 10^{-4} \cdot (w - 73)^{2}$$
$$-2.7953 \times 10^{-6} \cdot (w - 73)^{3} - 1.1566 \times 10^{-7} \cdot (w - 73)^{4} + 2.5969 \times 10^{-9} \cdot (w - 73)^{5})$$

The vapor permeability $\delta_p\left(SI \text{ unit: }s\right)$ used for the expression of the vapor flux, is defined as:

$$\delta_{\rm p} = \frac{M_{\rm w}}{R_{\rm H2O}T_{\rm ref}} \cdot \frac{26.1 \times 10^{-6}}{200} \cdot \frac{1 - \frac{w}{146}}{0.503 \left(1 - \frac{w}{146}\right)^2 + 0.497}$$

...

Thermal Properties

The equivalent thermal conductivity k_{eff} (SI unit: W/(m·K)) is defined as moisturedependent, with the following expression:

$$k_{\rm eff} = 1.5 + \frac{15.8}{1000}w$$

Finally, from the following data given by the norm for dry material:

$$\rho_s C_{p,s} = 1.824 \times 10^6$$

the density ρ_s of dry material is set to 2145.88 kg/m³, which corresponds to a value of $C_{p,s} = 850$ J/(kg·K), which is a typical value for concrete. Then the moisture-dependent equivalent heat capacity is defined as:

$$(\rho C_p)_{\text{eff}} = \rho_s C_{p,s} + w C_{p,w}$$

where $C_{p,w}$ is the (temperature dependent) water heat capacity at constant pressure.

Results and Discussion

The image below shows the temperature distribution at 7, 30, and 365 days, close to the left boundary of the domain. The norm data are represented by asterisks. You can verify that the numerical results are within the validity ranges for all control times.



Figure 1: Temperature distribution at 7, 30, and 365 days with Norm 15026 validity ranges

The image below shows the moisture storage function distribution at 7, 30, and 365 days, close to the left boundary of the domain. The norm data are represented by asterisks. You can verify that the numerical results are within the validity ranges for all control times.



Figure 2: Moisture storage function distribution at 7, 30, and 365 days with Norm 15026 validity ranges.

Reference

1. EN 15026, Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation, CEN, 2007.

Application Library path: Heat_Transfer_Module/Verification_Examples/ semi_infinite_wall

Modeling Instructions

From the File menu, choose New.

NEW

In the New window, click 🔗 Model Wizard.

MODEL WIZARD

- I In the Model Wizard window, click ID.
- 2 In the Select Physics tree, select Heat Transfer>Heat and Moisture Transport> Building Materials.
- 3 Click Add.
- 4 Click \bigcirc Study.
- 5 In the Select Study tree, select General Studies>Time Dependent.
- 6 Click 🗹 Done.

GLOBAL DEFINITIONS

Parameters 1

Define parameters for the temperature and relative humidity conditions on boundaries.

- I In the Model Builder window, under Global Definitions click Parameters I.
- 2 In the Settings window for Parameters, locate the Parameters section.
- **3** In the table, enter the following settings:

Name	Expression	Value	Description
T_e	30[degC]	303.15 K	Exterior temperature
phi_e	0.95	0.95	Exterior relative humidity
T_i	20[degC]	293.15 K	Interior temperature
phi_i	0.5	0.5	Interior relative humidity

Next, set the geometry.

GEOMETRY I

Interval I (i1)

- I In the Model Builder window, under Component I (comp1) right-click Geometry I and choose Interval.
- 2 In the Settings window for Interval, locate the Interval section.
- **3** In the table, enter the following settings:

Coordinates (m)			
0			
20			

Next, set the hygroscopic and thermal properties for the material specified in Norm 15026.

MATERIALS

Material - Norm 15026

- I In the Model Builder window, under Component I (compl) right-click Materials and choose Blank Material.
- 2 In the Settings window for Material, type Material Norm 15026 in the Label text field.
- 3 In the Model Builder window, expand the Component I (compl)>Materials>Material -Norm 15026 (matl) node.

Set the relative humidity as a physical quantity to be used in the material properties.

- 4 In the Model Builder window, under Component I (compl)>Materials>Material -Norm 15026 (matl) click Basic (def).
- 5 In the Settings window for Basic, locate the Model Inputs section.
- 6 Click + Select Quantity.
- 7 In the Physical Quantity dialog box, type relative humidity in the text field.
- 8 Click 🔫 Filter.
- 9 In the tree, select General>Relative humidity (1).
- IO Click OK.

Set the moisture content as a function of relative humidity.

Analytic: wc

- I In the Home toolbar, click f(X) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type Analytic: wc in the Label text field.
- 3 In the Function name text field, type wc.
- 4 Locate the **Definition** section. In the **Expression** text field, type 146/(1+(-8e-8*462* 293.15*1000*log(phi))^1.6)^0.375.
- 5 In the Arguments text field, type phi.

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the thermal conductivity as a function of the moisture content.

Analytic: k

- I In the Home toolbar, click f(x) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type Analytic: k in the Label text field.
- 3 In the Function name text field, type k.
- 4 Locate the Definition section. In the Expression text field, type 1.5+15.8e-3*w.
- 5 In the Arguments text field, type w.
- 6 Locate the Plot Parameters section. In the table, enter the following settings:

Argument	Lower limit	Upper limit	Unit
w	0	150	

You obtain the graph below.



Material - Norm 15026 (mat1) Set the suction stress as a function of the moisture content.

Analytic: s

- I In the Home toolbar, click f(X) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type Analytic: s in the Label text field.
- 3 In the Function name text field, type s.
- 4 Locate the **Definition** section. In the **Expression** text field, type 0.125e8*((146/w)^(1/0.375)-1)^0.625.
- 5 In the Arguments text field, type w.
- 6 Locate the Plot Parameters section. In the table, enter the following settings:

Argument	Lower limit	Upper limit	Unit
w	0	150	

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the liquid water permeability as a function of the moisture content.

Analytic: K

- I In the Home toolbar, click f(X) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type Analytic: K in the Label text field.
- 3 In the Function name text field, type K.
- 4 Locate the Definition section. In the Expression text field, type exp(-39.2619+0.0704* (w-146/2)-1.7420e-4*(w-146/2)^2-2.7953e-6*(w-146/2)^3-1.1566e-7*(w-146/2)^4+2.5969e-9*(w-146/2)^5).
- 5 In the Arguments text field, type w.
- 6 Locate the Plot Parameters section. In the table, enter the following settings:

Argument	Lower limit	Upper limit	Unit
w	0	150	

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the moisture diffusivity as a function of the suction stress and the liquid water permeability.

Analytic: Dw

- I In the Home toolbar, click f(X) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type Analytic: Dw in the Label text field.
- 3 In the Function name text field, type Dw.
- **4** Locate the **Definition** section. In the **Expression** text field, type -d(s(w), w) * K(w).
- 5 In the Arguments text field, type w.
- 6 Locate the Plot Parameters section. In the table, enter the following settings:

Argument	Lower limit	Upper limit	Unit
w	0	150	

You obtain the graph below.



Material - Norm 15026 (mat1)

Finally, set the vapor permeability as a function of the moisture content.

Analytic: delta_p

- I In the Home toolbar, click f(X) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type Analytic: delta_p in the Label text field.
- 3 In the Function name text field, type delta_p.
- 4 Locate the **Definition** section. In the **Expression** text field, type (0.01801528/R_const/293.15*26.1e-6/200*(1-w/146)/((1-0.497)*(1-w/146)^2+0.497)).
- 5 In the Arguments text field, type w.
- 6 Locate the Plot Parameters section. In the table, enter the following settings:

Argument	Lower limit	Upper limit	Unit
w	0	150	

Analytic: Dw (Dw)

I In the Model Builder window, click Analytic: Dw (Dw).

2 In the Settings window for Analytic, click 💿 Plot.

You obtain the graph below.



Material - Norm 15026 (mat1)

- I In the Model Builder window, under Component I (compl)>Materials click Material -Norm 15026 (matl).
- 2 In the Settings window for Material, locate the Material Contents section.
- **3** In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	k(wc(phi))	W/(m·K)	Basic
Density	rho	2145.88	kg/m³	Basic
Heat capacity at constant pressure	Ср	850	J/(kg·K)	Basic
Diffusion coefficient	D_iso ; Dii = D_iso, Dij = 0	Dw(wc(phi))	m²/s	Basic

Property	Variable	Value	Unit	Property group
Water content	w_c	wc(phi)	kg/m³	Basic
Vapor permeability	delta_p_iso; delta_pii = delta_p_iso, delta_pij = 0	delta_p(wc(phi))	S	Basic

Define a ramp function used to set a temperature and a relative humidity boundary condition consistent with the initial condition on the left boundary of the domain.

DEFINITIONS

Ramp I (rm I)

- I In the Home toolbar, click f(x) Functions and choose Local>Ramp.
- 2 In the Settings window for Ramp, locate the Parameters section.
- 3 In the Location text field, type 100.
- 4 In the Slope text field, type 1e-3.
- **5** Select the **Cutoff** check box.
- 6 Click to expand the Smoothing section. Select the Size of transition zone at start check box.
- 7 Select the Size of transition zone at cutoff check box.
- 8 In the Size of transition zone at start text field, type 100.
- 9 In the Size of transition zone at cutoff text field, type 100.

Now, set the physics interfaces.

HEAT TRANSFER IN BUILDING MATERIALS (HT)

Initial Values 1

- I In the Model Builder window, under Component I (compl)> Heat Transfer in Building Materials (ht) click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- **3** In the *T* text field, type T_i.

Temperature I

- I In the Physics toolbar, click Boundaries and choose Temperature.
- 2 Select Boundary 1 only.
- 3 In the Settings window for Temperature, locate the Temperature section.

4 In the T_0 text field, type T_i+(T_e-T_i)*rm1(t[1/s]).

Temperature 2

- I In the Physics toolbar, click Boundaries and choose Temperature.
- **2** Select Boundary 2 only.
- 3 In the Settings window for Temperature, locate the Temperature section.
- **4** In the T_0 text field, type T_i.

MOISTURE TRANSPORT IN BUILDING MATERIALS (MT)

Initial Values 1

- I In the Model Builder window, under Component I (compl)> Moisture Transport in Building Materials (mt) click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- **3** In the $\phi_{w,0}$ text field, type phi_i.

Moisture Content I

- I In the Physics toolbar, click Boundaries and choose Moisture Content.
- **2** Select Boundary 1 only.
- 3 In the Settings window for Moisture Content, locate the Moisture Content section.
- **4** In the T_0 text field, type $T_i+(T_e-T_i)*rm1(t[1/s])$.
- **5** In the $\phi_{w,0}$ text field, type phi_i+(phi_e-phi_i)*rm1(t[1/s]).

Moisture Content 2

- I In the Physics toolbar, click Boundaries and choose Moisture Content.
- **2** Select Boundary 2 only.
- 3 In the Settings window for Moisture Content, locate the Moisture Content section.
- **4** In the T_0 text field, type T_i.
- **5** In the $\phi_{w,0}$ text field, type phi_i.

Refine the mesh close to the boundary where exterior conditions are imposed.

MESH I

Edge IIn the **Mesh** toolbar, click \bigwedge **Edge**.

Distribution I

I Right-click Edge I and choose Distribution.

- 2 In the Settings window for Distribution, locate the Distribution section.
- 3 From the Distribution type list, choose Predefined.
- 4 In the Number of elements text field, type 1000.
- 5 In the Element ratio text field, type 25.
- 6 Click 📗 Build All.

Set the time-dependent study and compute.

STUDY I

Step 1: Time Dependent

- I In the Model Builder window, under Study I click Step I: Time Dependent.
- 2 In the Settings window for Time Dependent, locate the Study Settings section.
- 3 From the Time unit list, choose d.
- 4 In the **Output times** text field, type range(0,1,365).
- 5 From the Tolerance list, choose User controlled.
- 6 In the Relative tolerance text field, type 1e-3.
- **7** In the **Home** toolbar, click **= Compute**.

You can compare the results for the temperature and moisture storage function with the data of Norm EN 15026. First, import the validity ranges from the norm in tables.

RESULTS

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Table I
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- I In the **Results** toolbar, click **Table**.
- 2 In the Settings window for Table, locate the Data section.
- 3 Click Import.
- 4 Browse to the model's Application Libraries folder and double-click the file semi_infinite_wall_temperature.txt.

Table 2

- I In the **Results** toolbar, click **Table**.
- 2 In the Settings window for Table, locate the Data section.
- 3 Click Import.
- 4 Browse to the model's Application Libraries folder and double-click the file semi_infinite_wall_moisture_storage_function.txt.

To visualize the temperature distribution as in Figure 1, follow the next steps.

Temperature (ht)

- I In the Model Builder window, under Results click Temperature (ht).
- 2 In the Settings window for ID Plot Group, locate the Axis section.
- **3** Select the **Manual axis limits** check box.
- **4** In the **x minimum** text field, type **0**.
- 5 In the **x maximum** text field, type 6.
- 6 In the **y minimum** text field, type 19.
- 7 In the **y maximum** text field, type **30**.
- 8 Locate the Data section. From the Time selection list, choose From list.
- 9 In the Times (d) list, choose 7, 30, and 365.

Line Graph

- I In the Model Builder window, expand the Temperature (ht) node, then click Line Graph.
- 2 In the Settings window for Line Graph, locate the y-Axis Data section.
- 3 From the Unit list, choose degC.
- 4 Click to expand the Legends section. Select the Show legends check box.
- **5** In the **Temperature (ht)** toolbar, click **I** Plot.

Table Graph I

- I In the Model Builder window, right-click Temperature (ht) and choose Table Graph.
- 2 In the Settings window for Table Graph, locate the Coloring and Style section.
- **3** Find the Line style subsection. From the Line list, choose None.
- 4 From the Color list, choose From theme.
- 5 Find the Line markers subsection. From the Marker list, choose Asterisk.
- 6 In the Temperature (ht) toolbar, click 💽 Plot.

To visualize the moisture storage function distribution as in Figure 2, follow the next steps.

Moisture storage function

- I In the Model Builder window, under Results click Relative Humidity (mt).
- 2 In the Settings window for ID Plot Group, type Moisture storage function in the Label text field.
- 3 Locate the Axis section. Select the Manual axis limits check box.

- **4** In the **x minimum** text field, type **0**.
- **5** In the **x maximum** text field, type **0.11**.
- 6 In the **y minimum** text field, type 25.
- 7 In the **y maximum** text field, type 130.
- 8 Locate the Data section. From the Time selection list, choose From list.
- 9 In the Times (d) list, choose 7, 30, and 365.

Line Graph 1

- I In the Model Builder window, expand the Moisture storage function node, then click Line Graph I.
- 2 In the Settings window for Line Graph, locate the y-Axis Data section.
- 3 In the Expression text field, type mt.wc.
- 4 Locate the x-Axis Data section. From the Parameter list, choose Expression.
- **5** In the **Expression** text field, type **x**.
- 6 Locate the Legends section. Select the Show legends check box.
- 7 In the Moisture storage function toolbar, click **Plot**.

Table Graph 1

- I In the Model Builder window, right-click Moisture storage function and choose Table Graph.
- 2 In the Settings window for Table Graph, locate the Data section.
- 3 From the Table list, choose Table 2.
- **4** Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **None**.
- 5 From the Color list, choose From theme.
- 6 Find the Line markers subsection. From the Marker list, choose Asterisk.
- 7 In the Moisture storage function toolbar, click **O** Plot.

You can check that the results fit in the validity ranges given by the norm.