Created in COMSOL Multiphysics 5.6

Thermal Performances of Roller Shutters

Introduction

During the design of a building, environmental issues have gained considerable influence in the entire project. One of the first concerns is to improve thermal performances. In this process, simulation software provide key tools for modeling thermal losses and performances in the building.

The international standard ISO 10077-2:2012 (Ref. 1) deals with thermal performances of windows, doors, and shutters. It provides computed values of the thermal characteristics of frame profiles in order to validate a simulation software.

COMSOL Multiphysics successfully passes the entire benchmark. This document describes two test cases of ISO 10077-2:2012 related to roller shutters only. Other test cases from this standard are available in the following applications:

- Thermal Performances of Windows
- Glazing Influence on Thermal Performances of a Window

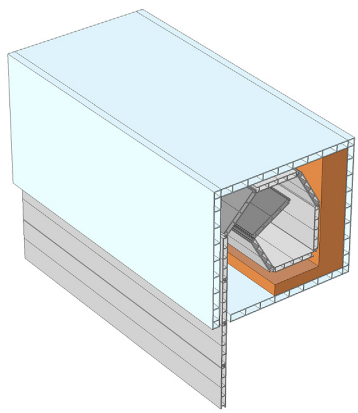

Figure 1: 3D representation of the roller shutter box with shutters inside.

Model Definition

On each test case, a shutter section separates a hot internal side from a cold external side. After solving a model, two quantities are calculated and compared to the normative values:

- the thermal conductance between the internal and external sides;
- the thermal transmittance of the shutter frame.

AIR CAVITIES

The roller shutter structure contains many cavities. The purpose is to ensure thermal insulation. According to the ISO 10077-2:2012 standard, cavities are modeled in different ways depending on their shapes.

The heat flow rate in cavities is represented by an equivalent thermal conductivity, k_{eq}, which includes the heat flow by conduction, convection, and radiation. It also depends on the geometry of the cavity and on the adjacent materials. The definition of k_{eq} is detailed in the next paragraphs.

Cavities are divided into three types:

- *unventilated cavities*, completely closed or connected either to the exterior or to the interior by a slit with a width not exceeding 2 mm;
- *slightly ventilated cavities*, connected either to the exterior or to the interior by a slit greater than 2 mm but not exceeding 10 mm;
- *well-ventilated cavities*: corresponding to a configuration not covered by one of the two preceding types, it is assumed that the whole surface is exposed to the environment so that boundary conditions are applied to (see the Boundary conditions section below for more information).

For the main cavity within a roller shutter box, these rules are slightly different (see Figure 2):

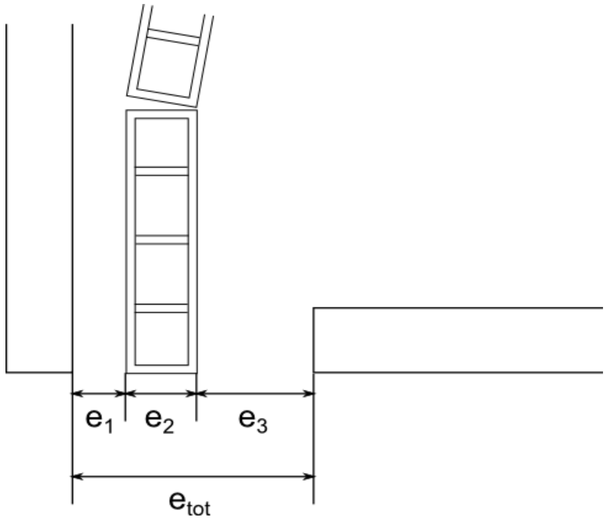

Figure 2: Opening of a roller shutter box.

- If $e_1 + e_3 \leq 2$ mm, the cavity is considered as *unventilated*.
- If $e_{tot} \leq 35$ mm, the cavity is considered as *slightly ventilated*.
- If $e_{tot} > 35$ mm, the cavity is considered as *well-ventilated*.

Unventilated Rectangular Cavity

For an unventilated rectangular cavity, the equivalent thermal conductivity is defined by:

$$k_{\mathrm{eq}} = \frac{d}{R}$$

where d is the cavity dimension in the heat flow rate direction, and R is the cavity thermal resistance given by:

$$R = \frac{1}{h_{\mathrm{a}} + h_{\mathrm{r}}}$$

Here, h_{a} is the convective heat transfer coefficient, and h_{r} is the radiative heat transfer coefficient. These coefficients are defined by:

$$h_a = \begin{cases} \dfrac{C_1}{d} & \text{if } b \le 5 \text{ mm} \\ \max\left(\dfrac{C_1}{d}, C_2 \Delta T^{1/3}\right) & \text{otherwise} \end{cases}$$

$$h_r = 4\sigma T_m^3 EF$$

where:

- $C_1 = 0.025$ W/(m·K)
- $C_2 = 0.73$ W/(m^2·K$^{4/3}$)
- ΔT is the maximum surface temperature difference in the cavity
- $\sigma = 5.67 \cdot 10^{-8}$ W/(m^2·K^4) is the Stefan-Boltzmann constant
- T_m is the average temperature on the boundaries of the cavity
- E is the intersurface emittance, defined by:

$$E = \frac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$$

- ε_1 and ε_2 are the surface emissivities (both are equal to 0.90 in this model)
- F is the view factor of the rectangular section, defined by:

$$F = \frac{1}{2}\left(1 - \frac{d}{b} + \sqrt{1 + \left(\frac{d}{b}\right)^2}\right)$$

- d is the cavity dimension in the heat flow rate direction
- b is the cavity dimension perpendicular to the heat flow rate direction

Slightly Ventilated Rectangular Cavities

For a slightly ventilated cavity, the equivalent thermal conductivity is twice that of an unventilated cavity of the same size.

Nonrectangular Cavities

Nonrectangular cavities are transformed into rectangular cavities of same area and aspect ratio according to defined rules in ISO 10077-2:2012 presented below. Then, k_{eq} is evaluated following one of the two previous rectangular cases.

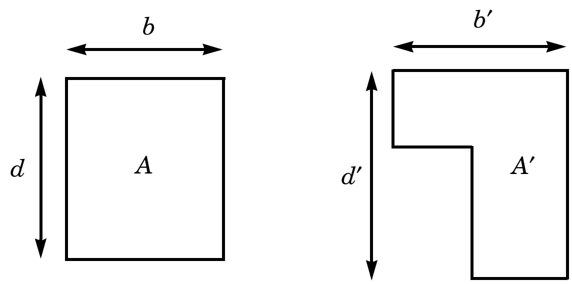

Figure 3: Nonrectangular cavity transformation.

Figure 3 shows a nonrectangular cavity of area A'. Then, d' and b' are the depth and the width (in accordance with the direction of the heat flow) of the smallest rectangle than can contain of the nonrectangular cavity. The equivalent rectangular cavity, of size $b \times d$ and area A must satisfy:

$$A = A' \qquad \frac{d}{b} = \frac{d'}{b'}$$

Hence, b and d are given by:

$$b = \sqrt{A'\frac{b'}{d'}} \qquad d = \sqrt{A'\frac{d'}{b'}}$$

BOUNDARY CONDITIONS

The heat flux conditions for internal and external sides are given by the Newton's law of cooling:

$$-\mathbf{n} \cdot (-k\nabla T) = h(T_{ext} - T)$$

where T_{ext} is the exterior temperature ($T_{ext} = T_i = 20°C$ for the internal side and $T_{ext} = T_e = 0°C$ for the external side). The standard defines thermal surface resistance, R_s, which is related to the heat transfer coefficient, h, by:

$$h = \frac{1}{R_s}$$

Internal and external thermal surface resistances are not equal.

DESCRIPTION OF THE TWO APPLICATIONS

Figure 4 and Figure 5 depict the geometry of each model. Unventilated cavities are red-numbered while slightly ventilated cavities are green-numbered. Adiabatic boundaries are represented with striped rectangles.

Application 1: Roller Shutter Box

The first application studies the heat conduction in a roller shutter box. The main structure is made of polyvinyl chloride (PVC) which has a low thermal conductivity k of 0.17 W/(m·K). Inside the box, there is an insulation panel which has a very low thermal conductivity of 0.035 W/(m·K).

In this application, there are thirty-eight cavities. Thirty-seven of them are not connected to the exterior so they are considered as *unventilated cavities*. The main cavity is considered as *slightly ventilated* because of the large opening in the box (15 mm).

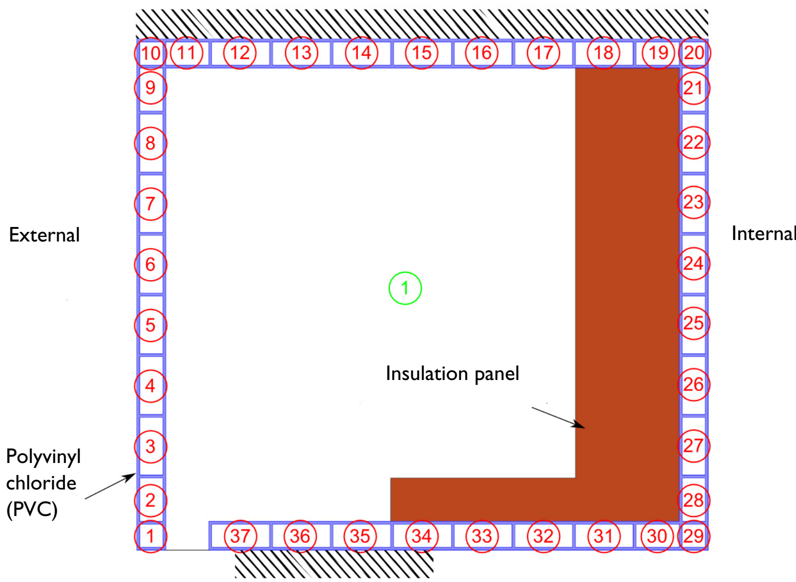

Figure 4: Geometry of the roller shutter box.

Application 2: PVC Shutter Profile

This application studies the heat conduction in a PVC shutter profile. The shutter is made of two PVC blocks which have a thermal conductivity of 0.17 W/(m·K).

In this application there are five cavities. They are not connected to the exterior so they are considered as *unventilated cavities*.

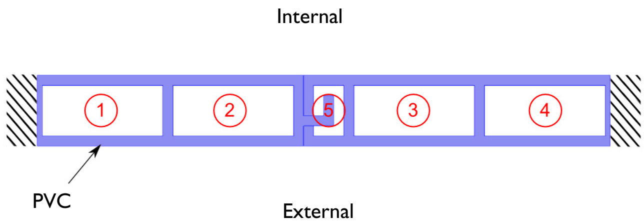

Figure 5: Geometry of the PVC shutter profile.

Results and Discussion

TEMPERATURE PROFILES

The temperature profiles for each model are shown in Figure 6 and Figure 7.

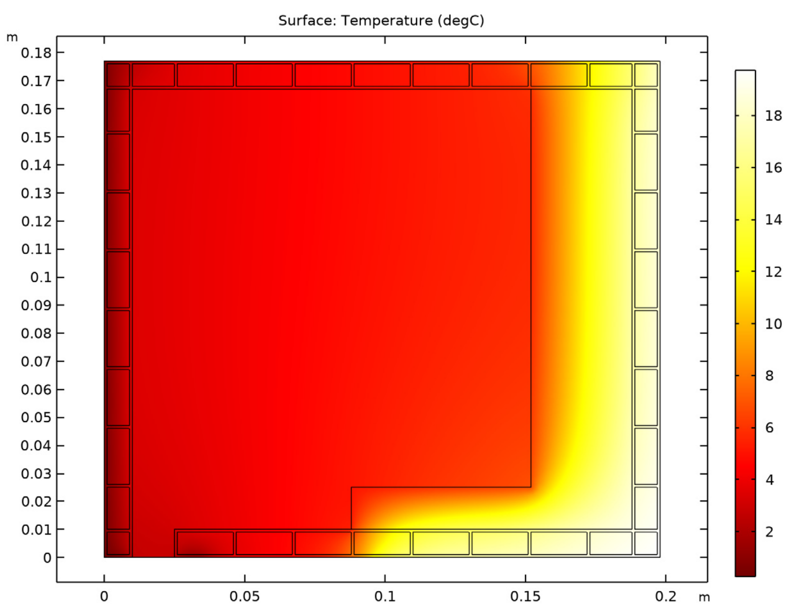

Figure 6: Temperature distribution in the roller shutter box.

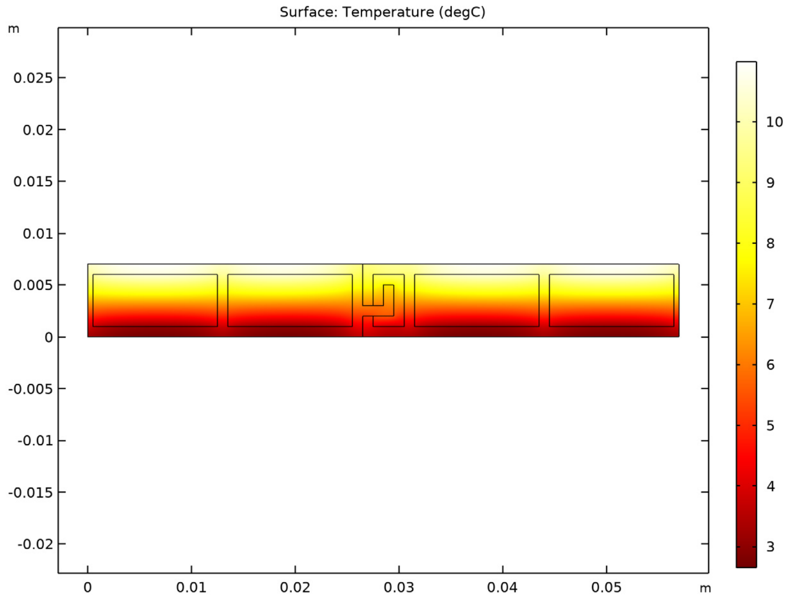

Figure 7: Temperature distribution in the PVC shutter profile.

QUANTITIES OF INTEREST

The quantities of interest are the following:

- The thermal conductance of the entire section, L^{2D}, given by:

$$L^{2D} = \frac{\phi}{T_e - T_i}$$

  where ϕ is the heat flow rate through the shutter (in W/m), $T_e = 0°C$ is the external temperature and $T_i = 20°C$ is the internal temperature.

- The thermal transmittance of the frame U_f defined by:

$$U_f = \frac{L^{2D}}{l}$$

  where l is the projected length of the internal section perpendicularly to the heat flow direction (expressed in meters).

Table 1 and Table 2 compare the numerical results of COMSOL Multiphysics with the expected values provided by ISO 10077-2:2012.

TABLE 1: COMPARISON BETWEEN EXPECTED VALUES AND COMPUTED VALUES OF QUANTITIES IN APPLICATION 1.

QUANTITY	EXPECTED VALUE	COMPUTED VALUE	RELATIVE ERROR
L^{2D} (W/(m·K))	0.181	0.183	1.10%
U_f (W/(m^2·K))	1.05	1.035	1.43%

TABLE 2: COMPARISON BETWEEN EXPECTED VALUES AND COMPUTED VALUES OF QUANTITIES IN APPLICATION 2.

QUANTITY	EXPECTED VALUE	COMPUTED VALUE	RELATIVE ERROR
L^{2D} (W/(m·K))	0.207	0.207	0.00%
U_f (W/(m^2·K))	3.64	3.63	0.27%

The maximum permissible differences to pass this test case are 3% for the thermal conductance and 5% for the thermal transmittance. The measured values are completely coherent and meet the validation criteria.

Reference

1. European Committee for Standardization, *ISO 10077-2:2012, Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames*, 2012.

Application Library path: `Heat_Transfer_Module/Buildings_and_Constructions/roller_shutter_thermal_performances`

Modeling Instructions

ROOT

Start by opening the following prepared file. It already contains global definitions, geometries, local variables, selections, operators and material properties.

1 From the **File** menu, choose **Open**.

2 Browse to the model's Application Libraries folder and double-click the file `roller_shutter_thermal_performances_preset.mph`.

ROLLER SHUTTER BOX (COMP1)

In the **Model Builder** window, expand the **Roller Shutter Box (comp1)** node.

DEFINITIONS (COMP1)

Variables 1

Define the thermal conductance of the section for the postprocessing part as follows.

1 In the **Model Builder** window, expand the **Roller Shutter Box (comp1)>Definitions** node, then click **Variables 1**.

2 In the **Settings** window for **Variables**, locate the **Variables** section.

3 In the table, enter the following settings:

Name	Expression	Unit	Description
L2D	int_internal(ht.ntflux /(Te-Ti))	W/(m·K)	Thermal conductance of the frame

Note that the heat flow rate through the internal and through the external boundaries are equal (in absolute value) because other boundaries are considered adiabatic.

4 In the **Model Builder** window, collapse the **Roller Shutter Box (comp1)>Definitions** node.

HEAT TRANSFER IN SOLIDS AND FLUIDS (HT)

Fluid 1

1 In the **Model Builder** window, expand the **Heat Transfer in Solids and Fluids (ht)** node, then click **Fluid 1**.

2 Select Domains 2–19 and 21–40 only.

As there is no convection, a second order discretization of the temperature is set for better accuracy.

3 In the **Model Builder** window, click **Heat Transfer in Solids and Fluids (ht)**.

4 In the **Settings** window for **Heat Transfer in Solids and Fluids**, click to expand the **Discretization** section.

5 From the **Temperature** list, choose **Quadratic Lagrange**.

Heat Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Exterior Side**.

4 Locate the **Heat Flux** section. Click the **Convective heat flux** button.

5 In the h text field, type `1/Rse`.

6 In the T_{ext} text field, type `Te`.

Heat Flux 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Interior Side**.

4 Locate the **Heat Flux** section. Click the **Convective heat flux** button.

5 In the h text field, type `1/Rsi`.

6 In the T_{ext} text field, type `Ti`.

7 In the **Model Builder** window, collapse the **Heat Transfer in Solids and Fluids (ht)** node.

STUDY 1

The heat flow rate through the interior (or exterior) side of the section needs to be determined to calculate the thermal conductance of the section. In order to have enough precision in this value, the default relative tolerance of the solver has already been modified to 10^{-6}. To access to this value, expand the **Solver 1** node and click on the **Stationary Solver 1** node. In the **Stationary Solver** settings window, locate the **General** section.

1 In the **Home** toolbar, click **Compute**.

RESULTS

Temperature (ht)

A **Global Evaluation** node is added in order to calculate the thermal conductance of the section and the thermal transmittance of the frame.

Thermal Properties, Roller Shutter Box

1 In the **Model Builder** window, expand the **Results>Derived Values** node.

2 Right-click **Derived Values** and choose **Global Evaluation**.

3 In the **Settings** window for **Global Evaluation**, type `Thermal Properties, Roller Shutter Box` in the **Label** text field.

4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
L2D	W/(m*K)	Thermal Conductance of the Section (L2D)
L2D/sb_htot	W/(m^2*K)	Thermal Transmittance of the Frame (Uf)

5 Click **Evaluate**.

TABLE

1 Go to the **Table** window.

The results should be close to the expected values in Table 1.

RESULTS

Surface

1 In the **Model Builder** window, expand the **Results>Temperature (ht)** node, then click **Surface**.

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 From the **Unit** list, choose **degC**.

4 In the **Temperature (ht)** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

The current plot group shows the temperature distribution; compare with Figure 6.

The same simulation method is applied to the other benchmark. The instructions below describe the steps to achieve the calculations.

PVC Shutter Profile

ROLLER SHUTTER BOX (COMP1)

In the **Model Builder** window, collapse the **Roller Shutter Box (comp1)** node.

PVC SHUTTER PROFILE (COMP2)

In the **Model Builder** window, expand the **PVC Shutter Profile (comp2)** node.

DEFINITIONS (COMP2)

Variables 2

1 In the **Model Builder** window, expand the **PVC Shutter Profile (comp2)>Definitions** node, then click **Variables 2**.

2 In the **Settings** window for **Variables**, locate the **Variables** section.

3 In the table, enter the following settings:

Name	Expression	Unit	Description
`L2D`	`int_internal(ht2.ntflux /(Te-Ti))`	W/(m·K)	`Thermal conductance of the frame`

4 In the **Model Builder** window, collapse the **PVC Shutter Profile (comp2)>Definitions** node.

HEAT TRANSFER IN SOLIDS AND FLUIDS 2 (HT2)

Fluid 1

1 In the **Model Builder** window, expand the **Heat Transfer in Solids and Fluids 2 (ht2)** node, then click **Fluid 1**.

2 Select Domains 2, 3, and 5–7 only.

As there is no convection, a second order discretization of the temperature is set for better accuracy.

3 In the **Model Builder** window, click **Heat Transfer in Solids and Fluids 2 (ht2)**.

4 In the **Settings** window for **Heat Transfer in Solids and Fluids**, click to expand the **Discretization** section.

5 From the **Temperature** list, choose **Quadratic Lagrange**.

Heat Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Exterior Side**.

4 Locate the **Heat Flux** section. Click the **Convective heat flux** button.

5 In the h text field, type `1/Rse`.

6 In the T_{ext} text field, type `Te`.

Heat Flux 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Interior Side**.

4 Locate the **Heat Flux** section. Click the **Convective heat flux** button.

5 In the h text field, type `1/Rsi`.

6 In the T_{ext} text field, type `Ti`.

7 In the **Model Builder** window, collapse the **Heat Transfer in Solids and Fluids 2 (ht2)** node.

STUDY 2

In the **Home** toolbar, click **Compute**.

RESULTS

A **Global Evaluation** node is added in order to calculate the thermal conductance of the section and the thermal transmittance of the frame.

Thermal Properties, PVC Shutter Profile

1 In the **Results** toolbar, click **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, type `Thermal Properties, PVC Shutter Profile` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 2/Solution 2 (4) (sol2)**.

4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
L2D	W/(m*K)	Thermal Conductance of the Section (L2D)
L2D/s_wtot	W/(m^2*K)	Thermal Transmittance of the Frame (Uf)

5 Click **Evaluate**.

TABLE

1 Go to the **Table** window.

The results should be close to the expected values in Table 2.

RESULTS

Surface

1 In the **Model Builder** window, expand the **Results>Temperature (ht2)** node, then click **Surface**.

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 From the **Unit** list, choose **degC**.

4 In the **Temperature (ht2)** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

The current plot group shows the temperature distribution; compare with Figure 7.