# Coopenergie metal structure insulation calculator – user guide and validation

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# 1 Introduction

The main purpose of this report is to describe the Coopenergie online tool for the calculation of thermal insulation in presence of metallic structures[1]. The second objective is to demonstrate the accuracy of the tool for calculating U or R values.

Such structures are commonly used for inside wall insulation, and their thermal resistance (R) or conductance (U) cannot easily be calculated as for wood structures.

Accurate values can only be obtained by 2D (or 3D) calculation, such as in the THERM[2] software. This is a quite powerful finite element software, but drawing the geometry is not intuitive and the drawn geometries are not parametric (i.e. simulating a slightly different case requires to redraw a part or the totality of the geometry). This software is not really “user friendly” (compared with today’s standards) to input the data.

The purpose of the Coopenergie online calculator is to provide a fast, user-friendly and parametric calculator to compute U-values of walls with metal structures.

Section 2 describes the user interface, the underlying hypotheses and the limitations of the calculator.

Section 3 compares the results of the calculator with results of THERM for a few cases.

Section 4 explains how calculator’s results should be used in in energy performance software (such as PACE or the EPB software).

# 2 Calculator description

## 2.1 Scope and limitations

The calculator is 2D only and can only compute U or R values for a succession of homogenous layers in the presence of one metallic profile.

As of today, only 3 sided rectangular like profiles can be simulated, with two different orientations. One of the underlying hypotheses is that the metal profile is very thin (usually 0.6mm) compared to the wall layers. It is not foreseen to compute thermal bridges of structural metal beams (HEA, etc). By default, the metal conductivity is 50 W/mK (steel).

Air layers cannot be computed in the tool. Therefore, the tool is limited to full walls or only to the layers of interest for hollow walls (the air layers must then be taken into account in the boundary conditions or in the global R/U value calculation).

1 https://www.coopenergie.be/index.php/article-test-menu/calculateur-ossature-metallique
2 https://windows.lbl.gov/software/therm

## 2.2 User interface and input parameters

The user interface consist in a web form with a graphical representation of the input data. The geometry updates automatically as the input parameters change. The user interface is shown in the Illustration 1 below, and the various inputs are described after.

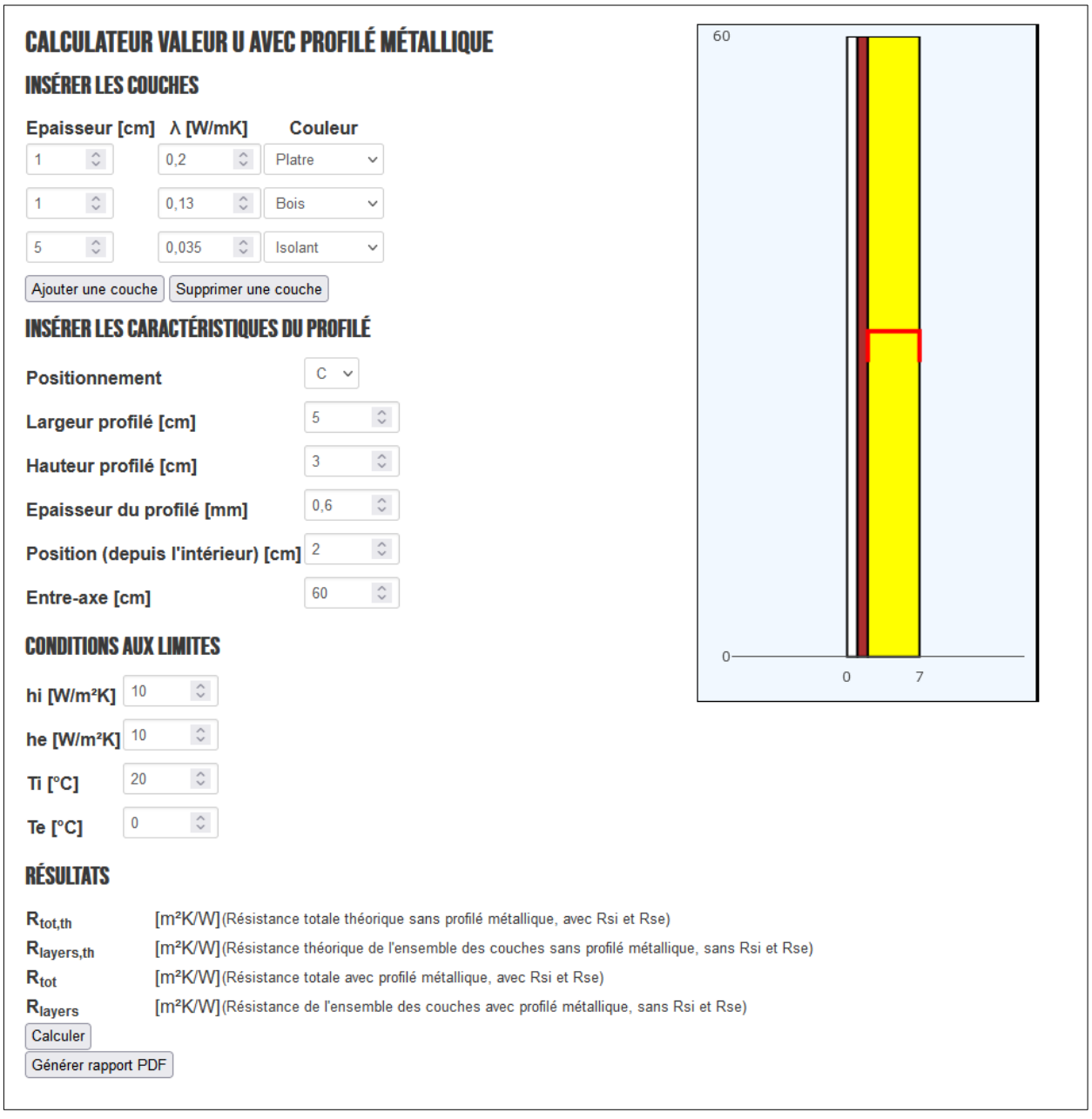



*Illustration 1: Web user interface*

There are 3 kinds of input to define: the wall layers, the metallic profile characteristics and position, and the boundary conditions.

- Layers
  - Number of material layers
  - For each layer (from interior to exterior, left to right)
    - thickness [cm]
    - thermal conductivity [W/mK]
    - a type of layer: wood, insulation, masonry or plaster (it has no impact on the calculation, it is only used to define the picture's colours)
- Metal profile (see Illustration 2)
  - Orientation (C-shape or U-shape,)
  - Profile width
  - Profile height
  - Profile thickness
  - Position of the profile from inside
  - Center distance between profiles
- Boundary conditions
  - hi: internal convection transfer coefficient
  - he: external convection transfer coefficient
  - Ti: internal temperature
  - Te: external temperature

A few important remarks:

- The metal thermal conductivity is fixed to 50 W/mK
- The dimensions of the profile are free, and do not necessary have to be entirely in one layer (and opposite). The user has to consistently define the parameters (with the help of the graphical representation, see User interface)
- The temperature do not impact the U or R values, they are only used for display purpose.

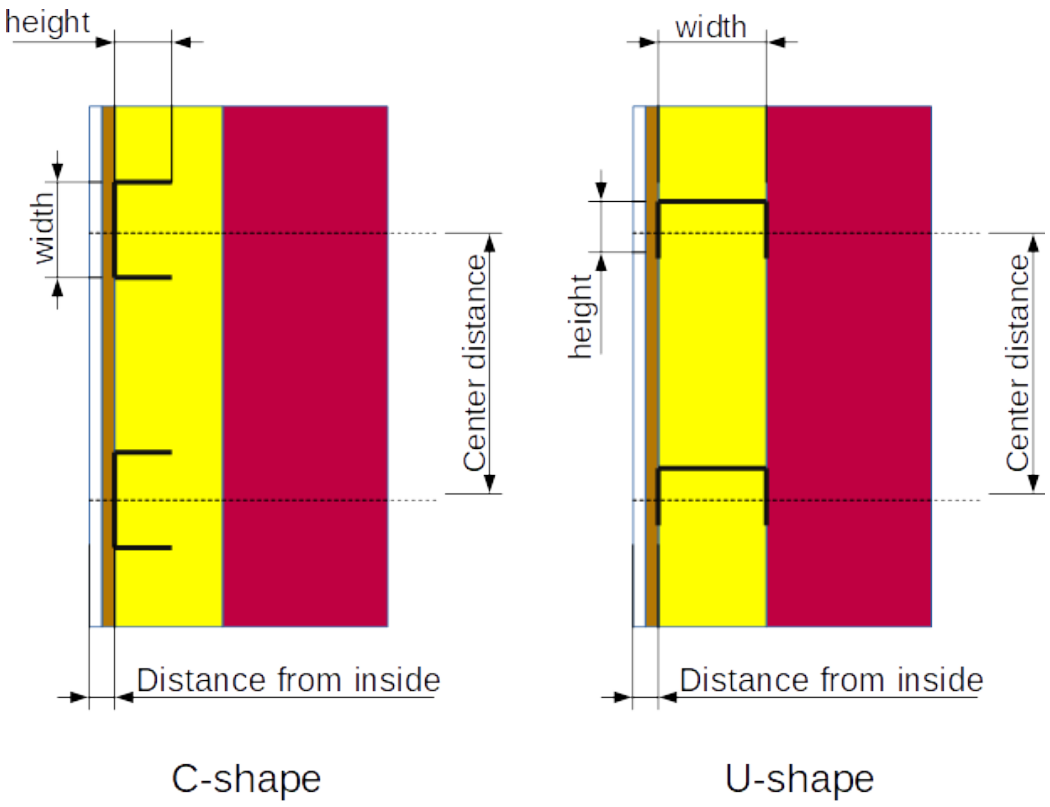
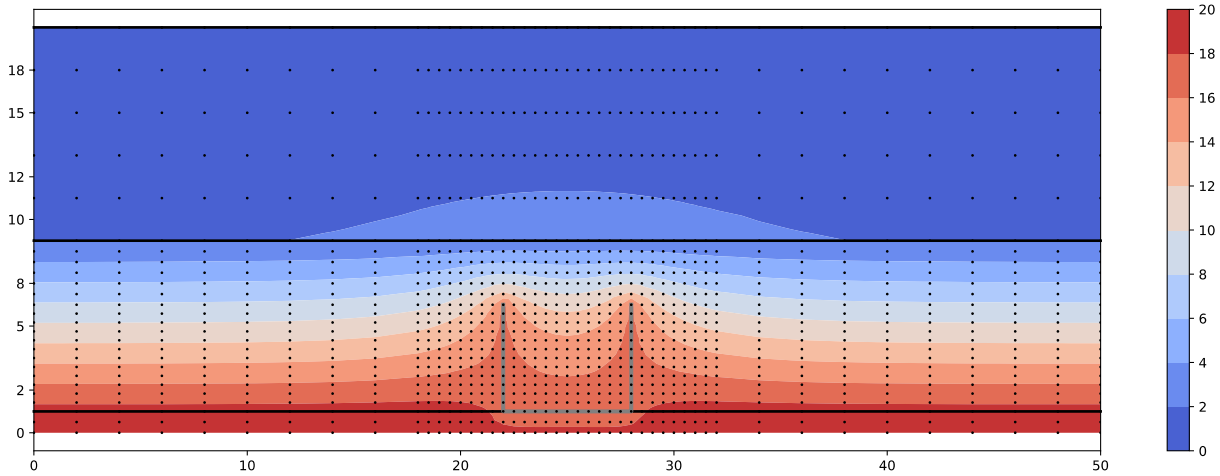



*Illustration 2: Position, size and orientation of the metallic profile. With and height are relative to the metallic profile itself, and not to the layers*

## 2.3 Underlying hypotheses and calculation method

The calculation is based on the 2D heat conduction equation. The calculation uses the finite difference method on a non-uniform structured mesh. The mesh size is automatically computed as a function of the layers thicknesses and the profile size and position. The mesh size is maximum 5 mm in the area of the metal profile, and 2 cm in the other regions.

The resulting mesh density is illustrated in an example below. Each dot is a computation node for the finite difference calculation. On can clearly see the increased mesh density in the region of the metallic profile (where the temperature variations are the most significant).




The volume of the metallic profile is not explicitly represented in the computational domain (geometrically, the profile is assumed infinitely thin). The heat conduction in the profile is solved by a 1-D heat conduction equation (taking into account the actual profile thickness). The results of the 1-D calculation are included in the main (2D) calculation, which insures both are coupled.

The 1-D hypothesis reasonable as long as the profile thickness is small compared to the other dimensions, and it makes it much easier and faster to compute than an explicit geometric representation. It

The global width of the domain is equal to the distance between two profiles (center distance). There is a symmetry boundary conditions applied on both sides.

# 3 Comparison with THERM

Several comparisons have been done between THERM calculation and the online calculator. They are detailed in the next pages with the various hypotheses (layers, conductivity, profile, etc) and a screenshot of both THERM and the online calculator results.

Here below a summary of the test cases. The compared values are the total resistance values including $R_{si}$ and $R_{se}$ ($1/h_i$ and $1/h_e$).

| Case | R value without metallic profile (analytic) | THERM R value with profile | Coopenergie online calculator R value with profile | Relative difference between THERM and Coopenergie |
|---|---|---|---|---|
| 1 | 3.13 | 2.8809 | 2.869 | -0.41% |
| 2 | 3.13 | 2.3814 | 2.390 | 0.36% |
| 3 | 3.334 | 3.08 | 3.095 | 0.49% |
| 4 | 1.705 | 0.8973 | 0.8741 | -2.59% |
| 5 | 1.544 | 1.2729 | 1.275 | 0.16% |

The difference between the online calculator and THERM is < 1% four 4 out of 5 cases, and < 3% for the worst case.

The worst case is the one with the smallest thermal resistance, where the metallic profile is directly in contact with the boundary condition (it should not happen in practice and is a little bit singular from a numerical point of view).

## 3.1 Case 1

Layers:

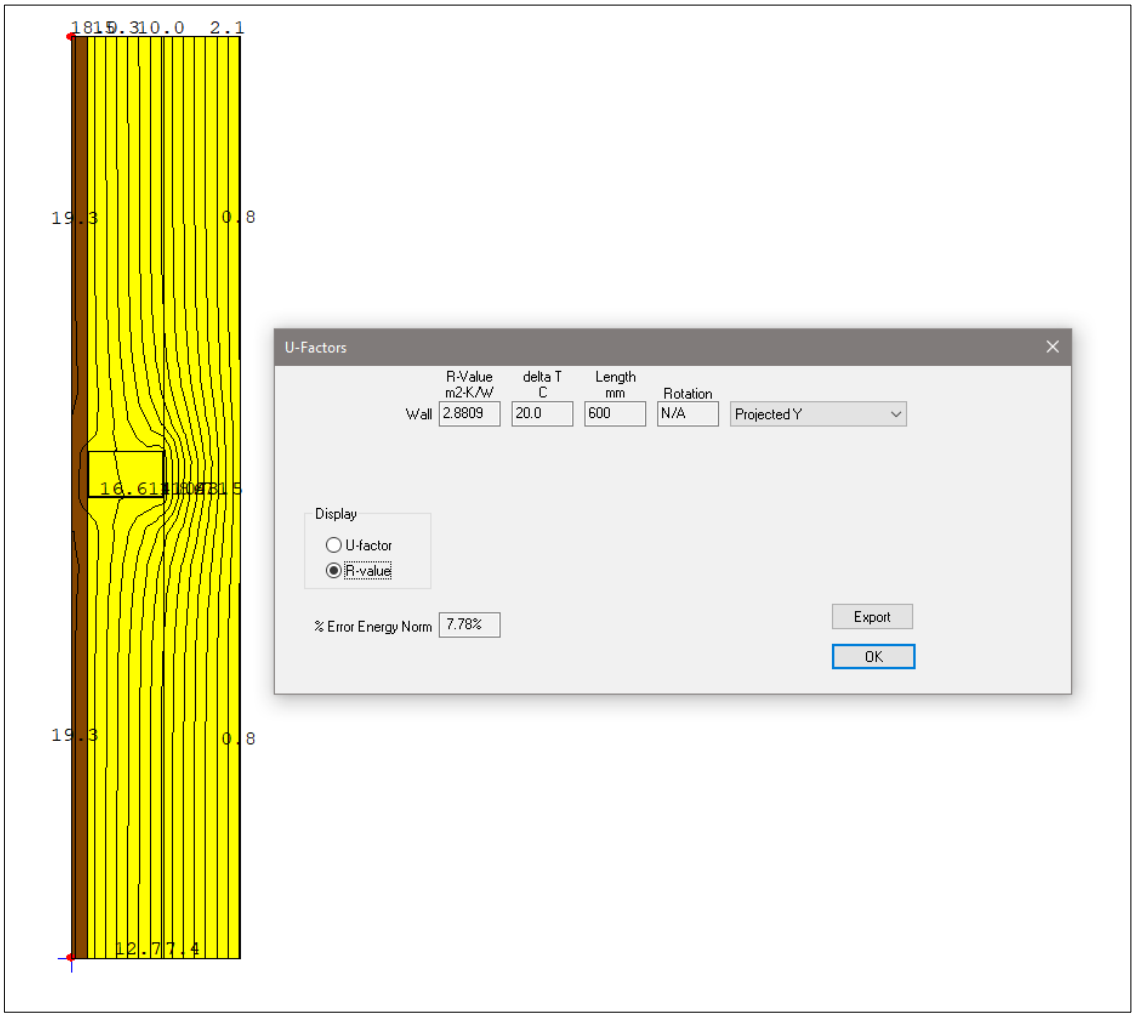
- 1 cm wood (λ = 0.13 W/mK)
- 10 cm MW (λ = 0.035 W/mK)

Profile:

- C-shape
- thickness: 0.6 mm
- Width: 5 cm
- Height: 3 cm
- Center distance: 60 cm

Boundary conditions:

- he = hi = 10 W/m²K




## CALCULATEUR VALEUR U AVEC PROFILÉ MÉTALLIQUE

### INSÉRER LES COUCHES

| Epaisseur [cm] | λ [W/mK] | Couleur |
|---|---|---|
| 1 | 0.13 | Bois |
| 10 | 0.035 | Isolant |

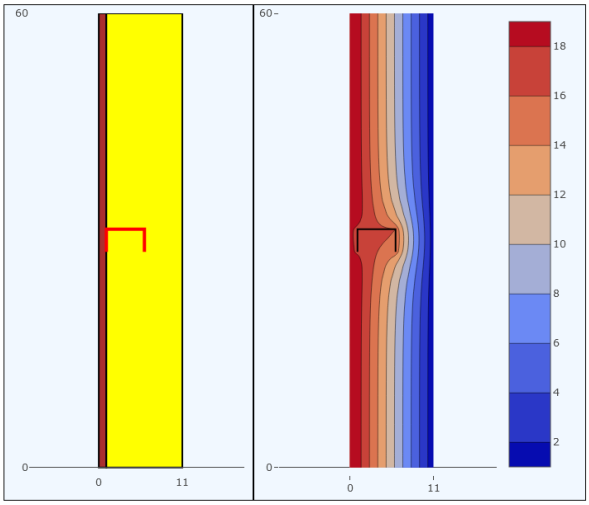
Ajouter une couche | Supprimer une couche

### INSÉRER LES CARACTÉRISTIQUES DU PROFILÉ

| | |
|---|---|
| Positionnement | C |
| Largeur profilé [cm] | 5 |
| Hauteur profilé [cm] | 3 |
| Epaisseur du profilé [mm] | 0,6 |
| Position (depuis l'intérieur) [cm] | 1 |
| Entre-axe [cm] | 60 |

### CONDITIONS AUX LIMITES

| | |
|---|---|
| hi [W/m²K] | 10 |
| he [W/m²K] | 10 |
| Ti [°C] | 20 |
| Te [°C] | 0 |




### RÉSULTATS

$R_{tot,th}$ 3.134 [m²K/W] (Résistance totale théorique sans profilé métallique, avec Rsi et Rse)
$R_{layers,th}$ 2.934 [m²K/W] (Résistance théorique de l'ensemble des couches sans profilé métallique, sans Rsi et Rse)
$R_{tot}$ 2.896 [m²K/W] (Résistance totale avec profilé métallique, avec Rsi et Rse)
$R_{layers}$ 2.696 [m²K/W] (Résistance de l'ensemble des couches avec profilé métallique, sans Rsi et Rse)

Calculer
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## 3.2 Case 2

Layers:

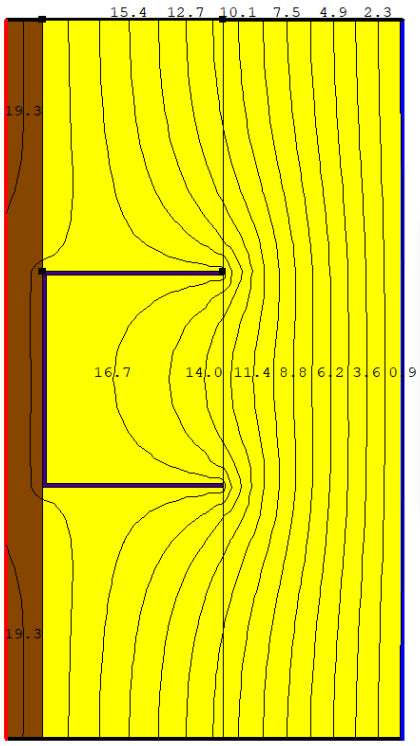
- 1 cm wood (λ = 0.13 W/mK)
- 10 cm MW (λ = 0.035 W/mK)

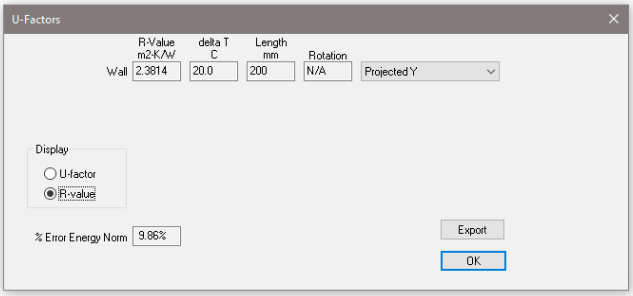
Profile:

- U-shape
- thickness: 1.0 mm
- Width: 6 cm
- Height: 5 cm
- Center distance: 20 cm

Boundary conditions:

- he = hi = 10 W/m²K




## CALCULATEUR VALEUR U AVEC PROFILÉ MÉTALLIQUE

### INSÉRER LES COUCHES

| Epaisseur [cm] | λ [W/mK] | Couleur |
|---|---|---|
| 1 | 0.13 | Bois |
| 10 | 0.035 | Isolant |

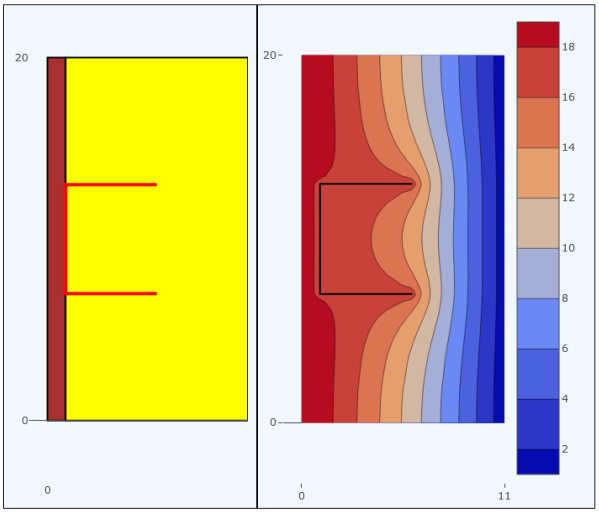
Ajouter une couche | Supprimer une couche

### INSÉRER LES CARACTÉRISTIQUES DU PROFILÉ

| | |
|---|---|
| Positionnement | U |
| Largeur profilé [cm] | 6 |
| Hauteur profilé [cm] | 5 |
| Epaisseur du profilé [mm] | 1 |
| Position (depuis l'intérieur) [cm] | 1 |
| Entre-axe [cm] | 20 |

### CONDITIONS AUX LIMITES

| | |
|---|---|
| hi [W/m²K] | 10 |
| he [W/m²K] | 10 |
| Ti [°C] | 20 |
| Te [°C] | 0 |




### RÉSULTATS

$R_{tot,th}$ 3.134 [m²K/W] (Résistance totale théorique sans profilé métallique, avec Rsi et Rse)
$R_{layers,th}$ 2.934 [m²K/W] (Résistance théorique de l'ensemble des couches sans profilé métallique, sans Rsi et Rse)
$R_{tot}$ 2.390 [m²K/W] (Résistance totale avec profilé métallique, avec Rsi et Rse)
$R_{layers}$ 2.190 [m²K/W] (Résistance de l'ensemble des couches avec profilé métallique, sans Rsi et Rse)

Calculer
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## 3.3 Case 3

Layers:

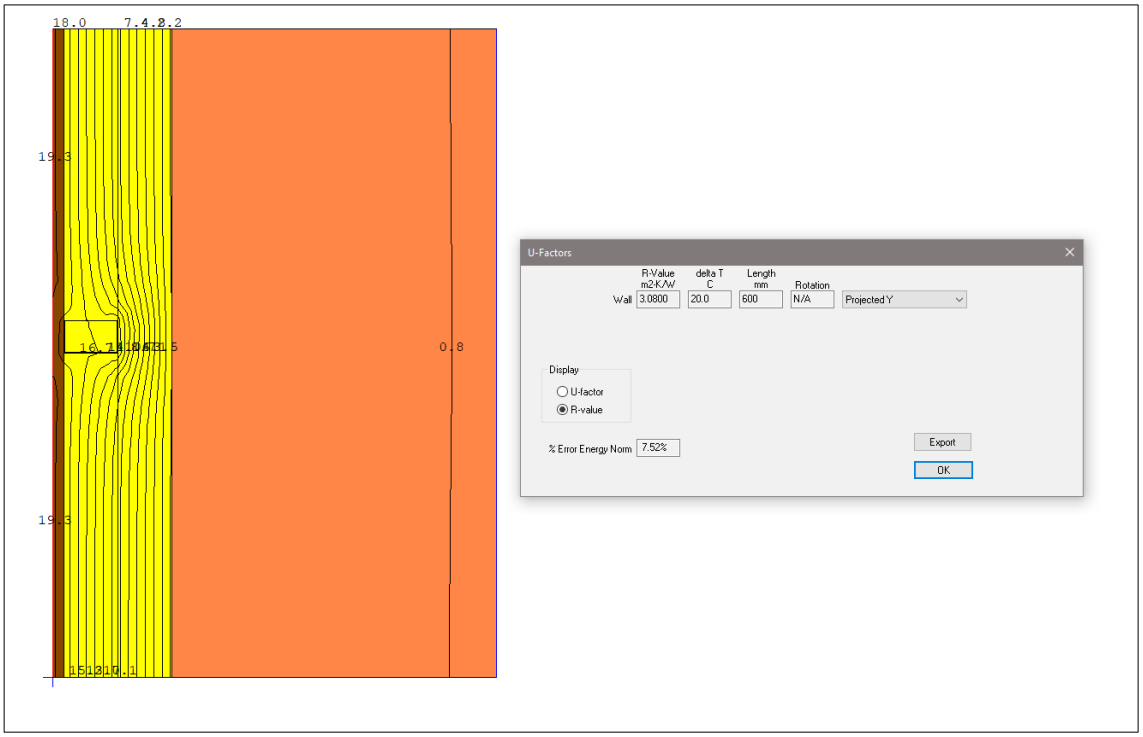
- 1 cm wood (λ = 0.13 W/mK)
- 10 cm MW (λ = 0.035 W/mK)
- 30 cm masonry ( λ = 1.5 W/mK)

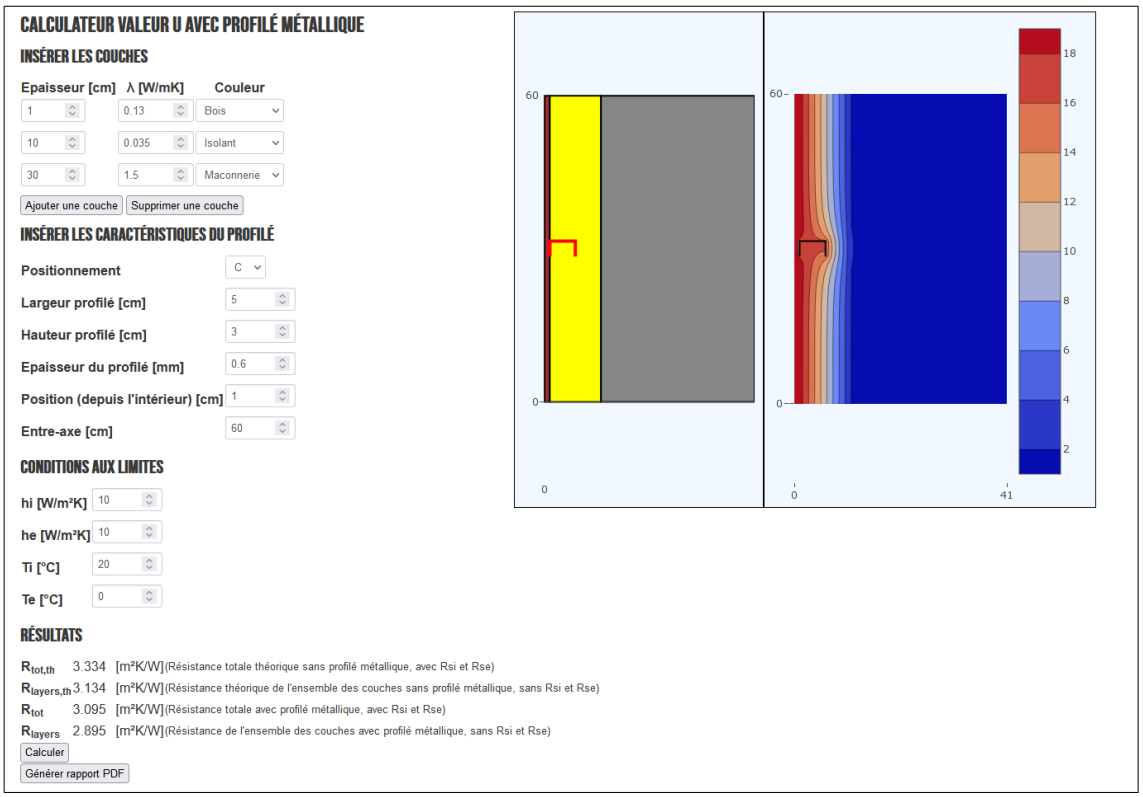
Profile:

- C-shape
- thickness: 0.6 mm
- Width: 5 cm
- Height: 3 cm
- Center distance: 60 cm

Boundary conditions:

- he = hi = 10 W/m²K


18.0
7.4.2.2
19.3
0.8
19.3
15.12.10.1
U-Factors
R-Value m2.K/W
delta T C
Length mm
Rotation
Wall
3.0800
20.0
600
N/A
Projected Y
Display
U-factor
R-value
% Error Energy Norm
7.52%
Export
OK


CALCULATEUR VALEUR U AVEC PROFILÉ MÉTALLIQUE
INSÉRER LES COUCHES
Epaisseur [cm]
λ [W/mK]
Couleur
1
0.13
Bois
10
0.035
Isolant
30
1.5
Maconnerie
Ajouter une couche
Supprimer une couche
INSÉRER LES CARACTÉRISTIQUES DU PROFILÉ
Positionnement
C
Largeur profilé [cm]
5
Hauteur profilé [cm]
3
Epaisseur du profilé [mm]
0.6
Position (depuis l'intérieur) [cm]
1
Entre-axe [cm]
60
CONDITIONS AUX LIMITES
hi [W/m²K]
10
he [W/m²K]
10
Ti [°C]
20
Te [°C]
0
RÉSULTATS
Rtot,th 3.334 [m²K/W] (Résistance totale théorique sans profilé métallique, avec Rsi et Rse)
Rlayers,th 3.134 [m²K/W] (Résistance théorique de l'ensemble des couches sans profilé métallique, sans Rsi et Rse)
Rtot 3.095 [m²K/W] (Résistance totale avec profilé métallique, avec Rsi et Rse)
Rlayers 2.895 [m²K/W] (Résistance de l'ensemble des couches avec profilé métallique, sans Rsi et Rse)
Calculer
Générer rapport PDF
60
0
0
60
0
0
41
18
16
14
12
10
8
6
4
2

## 3.4 Case 4

Layers:

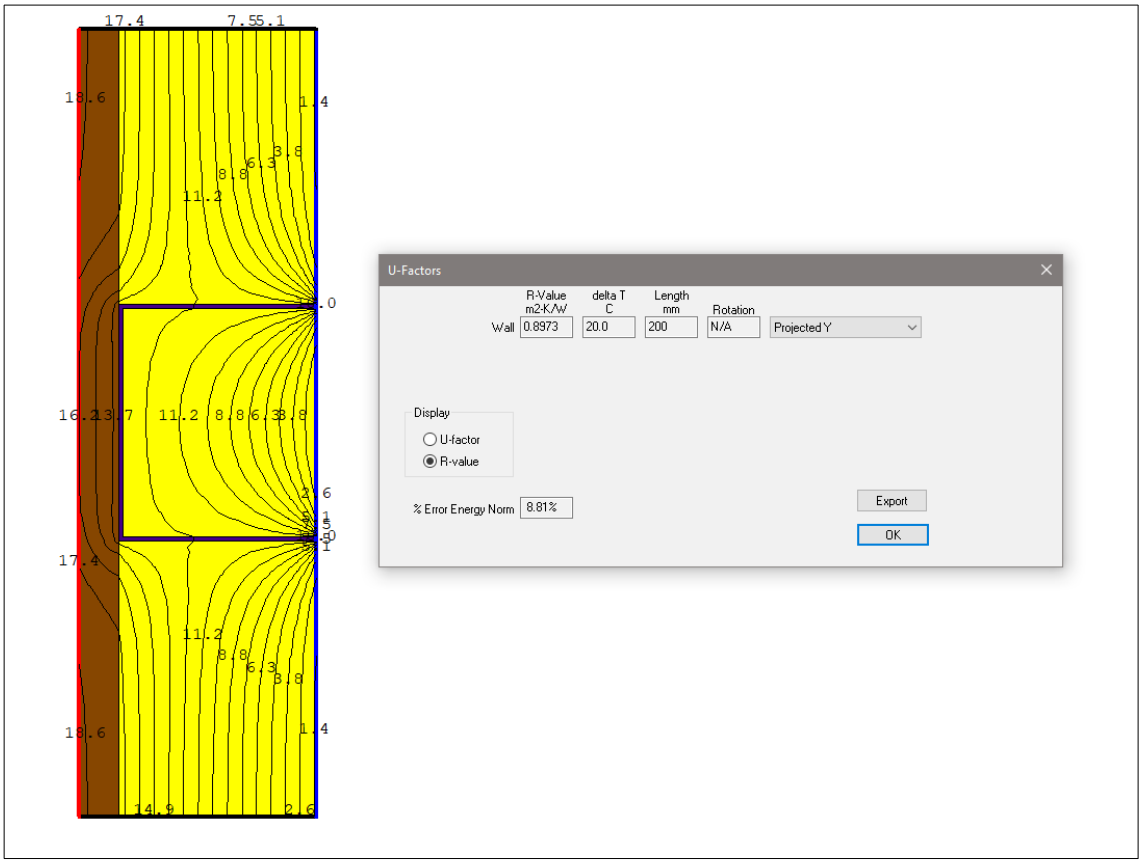
- 1 cm wood (λ = 0.13 W/mK)
- 5cm MW (λ = 0.035 W/mK)

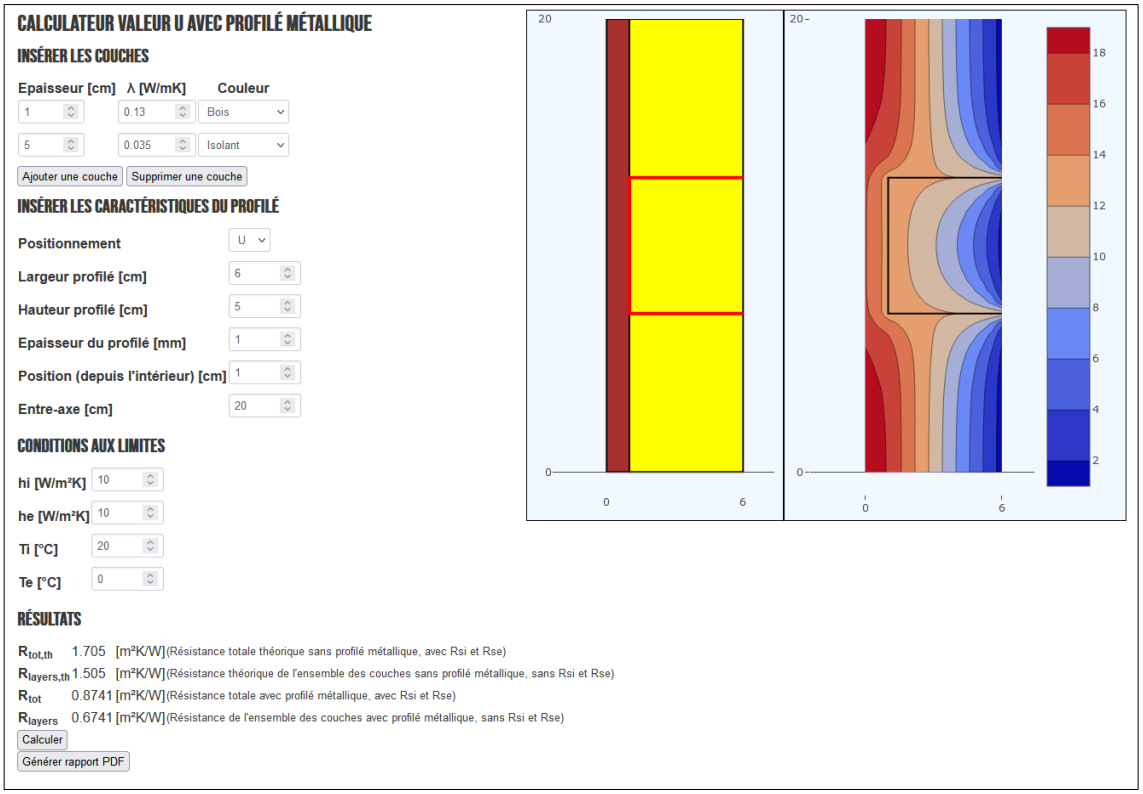
Profile:

- U-shape
- thickness: 1 mm
- Width: 6 cm
- Height: 5 cm
- Center distance: 20 cm

Boundary conditions:

- he = hi = 10 W/m²K


U-Factors
R-Value m2-K/W
delta T C
Length mm
Rotation
Wall
0.8973
20.0
200
N/A
Projected Y
Display
U-factor
R-value
% Error Energy Norm
8.81%
Export
OK


CALCULATEUR VALEUR U AVEC PROFILÉ MÉTALLIQUE
INSÉRER LES COUCHES
Epaisseur [cm]
λ [W/mK]
Couleur
1
0.13
Bois
5
0.035
Isolant
Ajouter une couche
Supprimer une couche
INSÉRER LES CARACTÉRISTIQUES DU PROFILÉ
Positionnement
U
Largeur profilé [cm]
6
Hauteur profilé [cm]
5
Epaisseur du profilé [mm]
1
Position (depuis l'intérieur) [cm]
1
Entre-axe [cm]
20
CONDITIONS AUX LIMITES
hi [W/m²K]
10
he [W/m²K]
10
Ti [°C]
20
Te [°C]
0
RÉSULTATS
Rtot,th 1.705 [m²K/W](Résistance totale théorique sans profilé métallique, avec Rsi et Rse)
Rlayers,th 1.505 [m²K/W](Résistance théorique de l'ensemble des couches sans profilé métallique, sans Rsi et Rse)
Rtot 0.8741 [m²K/W](Résistance totale avec profilé métallique, avec Rsi et Rse)
Rlayers 0.6741 [m²K/W](Résistance de l'ensemble des couches avec profilé métallique, sans Rsi et Rse)
Calculer
Générer rapport PDF

## 3.5 Case 5

Layers:

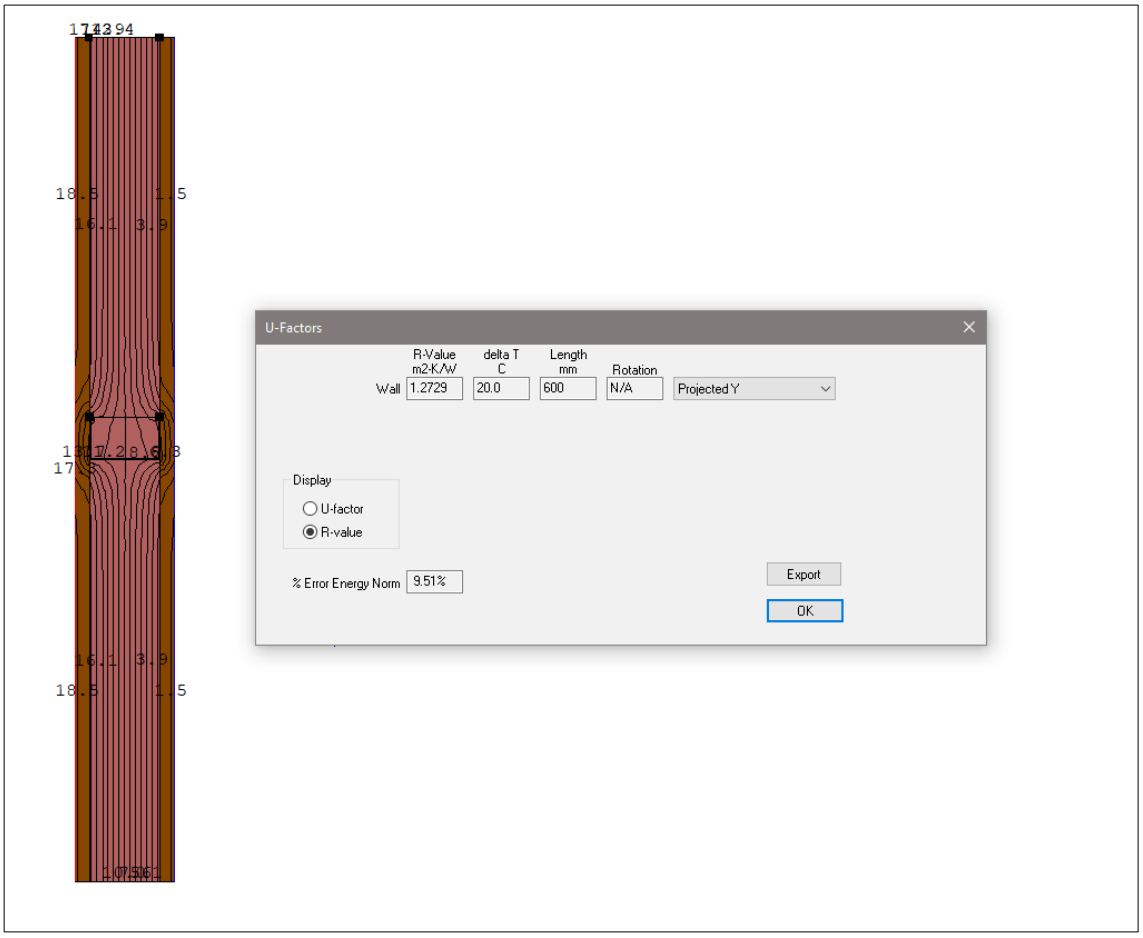
- 1 cm wood (λ = 0.13 W/mK)
- 5cm Wood fiber (λ = 0.042 W/mK)

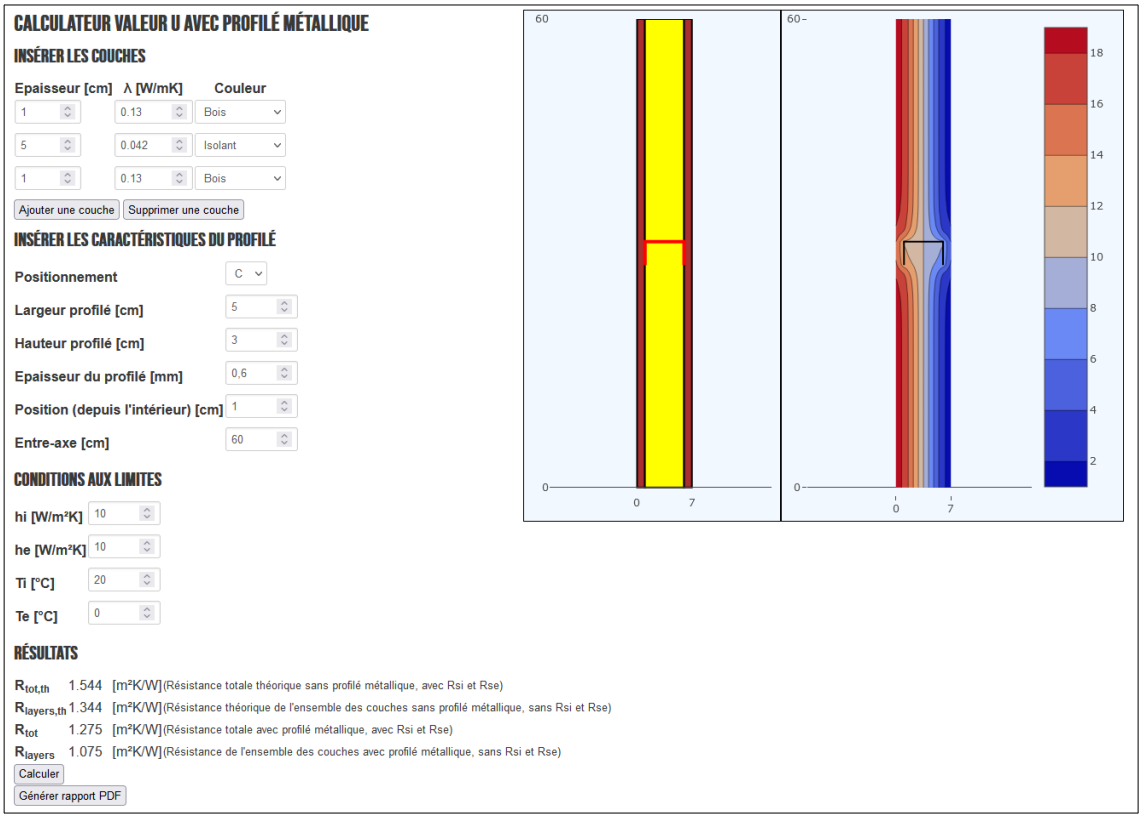
Profile:

- C-shape
- thickness: 0.6 mm
- Width: 5 cm
- Height: 3 cm
- Center distance: 60 cm

Boundary conditions:

- he = hi = 10 W/m²K


U-Factors
R-Value m2-K/W
delta T C
Length mm
Rotation
Wall
1.2729
20.0
600
N/A
Projected Y
Display
U-factor
R-value
% Error Energy Norm
9.51%
Export
OK


CALCULATEUR VALEUR U AVEC PROFILÉ MÉTALLIQUE
INSÉRER LES COUCHES
Epaisseur [cm]
λ [W/mK]
Couleur
1
0.13
Bois
5
0.042
Isolant
1
0.13
Bois
Ajouter une couche
Supprimer une couche
INSÉRER LES CARACTÉRISTIQUES DU PROFILÉ
Positionnement
C
Largeur profilé [cm]
5
Hauteur profilé [cm]
3
Epaisseur du profilé [mm]
0,6
Position (depuis l'intérieur) [cm]
1
Entre-axe [cm]
60
CONDITIONS AUX LIMITES
hi [W/m²K]
10
he [W/m²K]
10
Ti [°C]
20
Te [°C]
0
RÉSULTATS
Rtot,th 1.544 [m²K/W] (Résistance totale théorique sans profilé métallique, avec Rsi et Rse)
Rlayers,th 1.344 [m²K/W] (Résistance théorique de l'ensemble des couches sans profilé métallique, sans Rsi et Rse)
Rtot 1.275 [m²K/W] (Résistance totale avec profilé métallique, avec Rsi et Rse)
Rlayers 1.075 [m²K/W] (Résistance de l'ensemble des couches avec profilé métallique, sans Rsi et Rse)
Calculer
Générer rapport PDF

# 4 How to include the results of the calculator in PACE or EPB software

## 4.1 Introduction – general rationale

In software such as PACE or the EPB software, the total thermal resistance is computed by summing up the thermal resistance of the various layers. This layer decomposition is also very useful for the final client (explicit description of the various materials and their thickness).

When there is a thermal bridge with a metal structure, this addition is not perfectly correct since there is also an impact on the temperature profile in the neighbouring layers. But for the sake of clarity, it is better if all layers appear explicitly.

To include the results of a 2D calculation in the layer by layer description, the following approach is advised:

- Perform the 2D calculation of the whole wall (include all layers – if possible)
- Compute the $\Delta R = R_{total,theoricial} - R_{total,\ 2D\ calculation}$
- Introduce all layers in the EPB/PACE software with the correct thickness and conductivity
- For the layer containing the metallic profile, manually insert the thermal resistance:
  - $R_{layer} = R_{layer,theoritical} - \Delta R = e_{layer}/\lambda_{layer} - \Delta R$

Let's apply it to an example: a full brick wall (30 cm) with 10 cm insulation (5 continuous, 5 in metal structure). See exact wall composition, profile and calculation results in Illustration 5.

The theoretical wall resistance (without $R_{si}$ and $R_{se}$) is 3.184 m²K/W. The actual thermal resistance computed by the 2D model is 2.940 m²K/W.

The ΔR is thus (3.18-2.940) = 0.244 m²K/W. This Δ should be accounted in the layer containing the metallic profile. The resistance of this layer is thus 1.428-0.244 = 1.184 m²K/W.

The following data should be introduced in the EPB/PACE software

*Table 1: Layers to be introduced in EPB/PACE software - example*

| **Layer** | **e[cm]** | **λ [W/mK]** | **R [m²K/W]** |
|---|---|---|---|
| Bricks | 30 | 1.5 | 0.2 |
| MW (continuous) | 0.05 | 0.035 | 1.428 |
| MW (in metallic profile) | 0.05 | 0.035 | 1.184* |
| OSB | 1 | 0.13 | 0.076 |

| | | | |
|---|---|---|---|
| Platre | 1 | 0.2 | 0.05 |
| * value set manually from external calculation | | | |

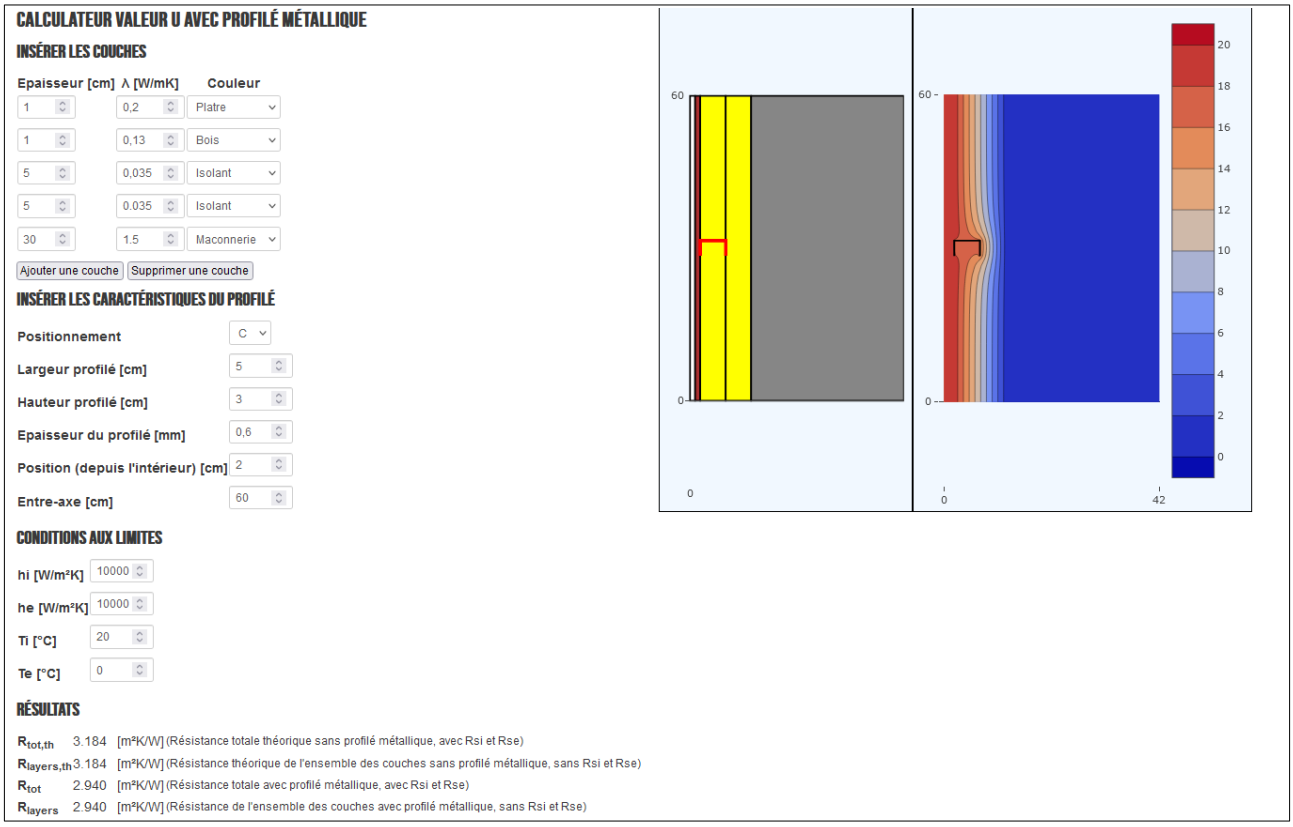



*Illustration 3: How to use the 2D results in EPB/PACE calculation - example*

## 4.2 Model the whole wall or only some layers?

The rationale of the previous section could also be applied without modelling the full wall, but modelling only some of the layers. This is done in the example below, modelling only the plaster, the wood and the first insulation layer.

If doing so (see Illustration 4), the computed ΔR is 0.536 (1.555 – 1.019). It is more than two times bigger than in the previous section, for the exact same geometry (5 cm MW with metallic profile).

It is because the true impact of the metal profile is larger than only the 5 cm MW layer. This is correctly modelled in Illustration 3, but in the calculation of Illustration 4 a constant temperature boundary condition is forced close to the metal profile. Doing so is always conservative (i.e. on the safe side).

Therefore recommendation is to take into account as much layers as possible as this is more accurate (and also more favourable as it gives higher R values).

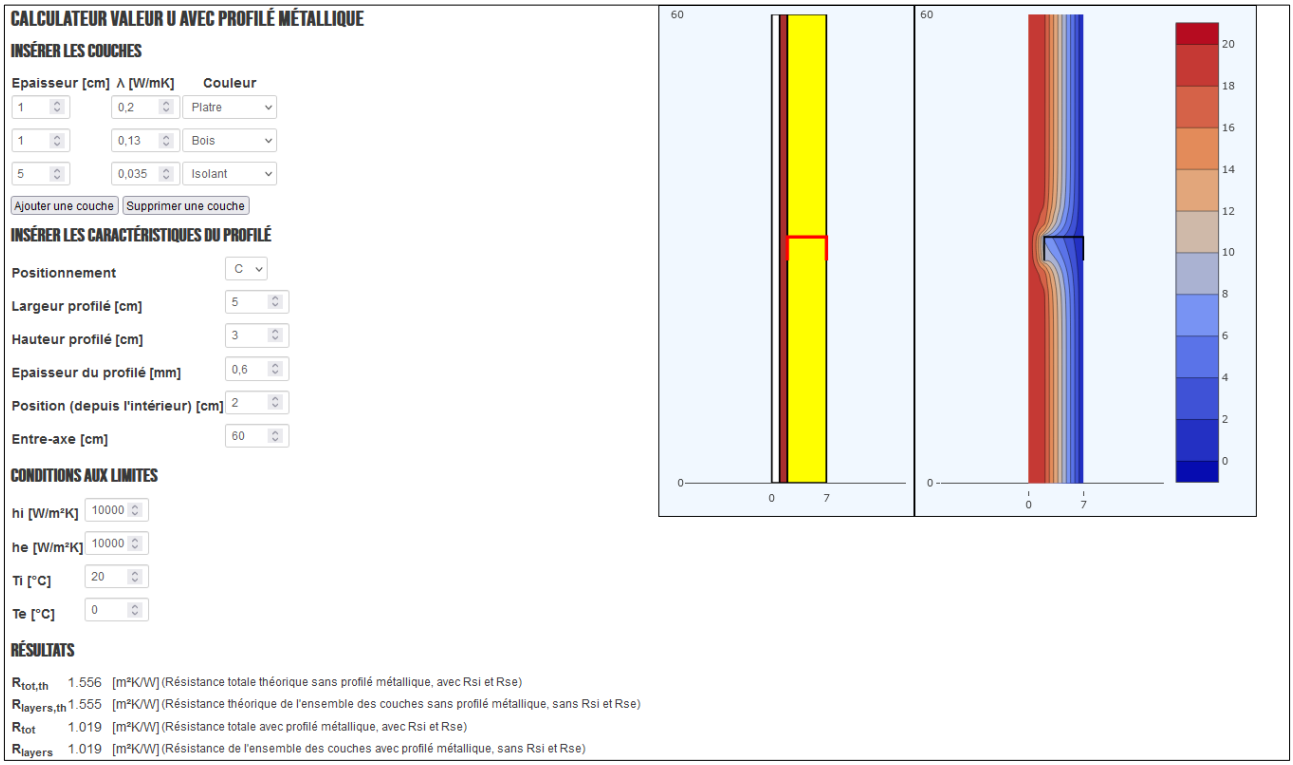



*Illustration 4: Example when modelling only one part of the layers*

## 4.3 Air layers and heterogeneous materials

Air layers cannot directly be solved in such finite element calculator, since the heat transfer do not occur by heat conduction, but by convection. This is also the case for heterogeneous elements such as hollow concrete blocks or hollow bricks.

In that case, it is recommanded to model as much layers as possible, but to stop at the air layer (or heterogeneous layer). The thermal resistance of the air/heterogeneous layer (and other layers on the other side) have to be added manually or directly in the EPB/PACE software.

**Example**

Lets consider a hollow wall with a cellular concrete block, an air layer and a facing brick. Lets assume it is insulated by the inside, with a continuous MW layer, and a second layer within a metal structure as illustrated below.

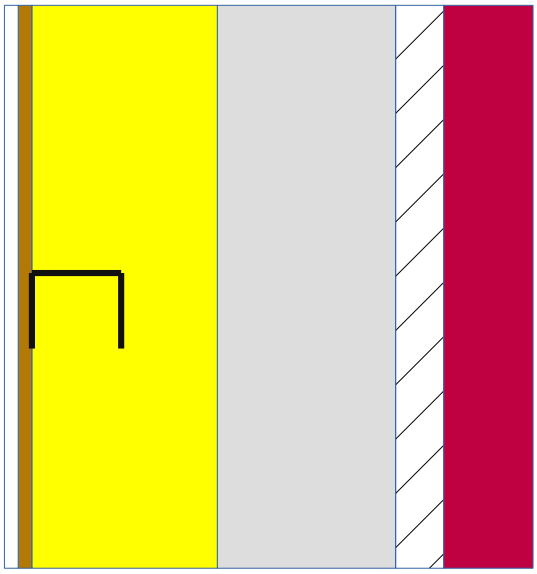


*Illustration 5: Example wall composition with an air layer (white: plaster, yellow: MW, grey: cellular concreted, hatched: air layer, red: facing brick)*

The air layer and the facing brick cannot be modelled. The model will go from the plaster to the cellular block. The result of the 2D calculation is given in Illustration 6.

The theoretical resistance is 3.734 and the actual computed resistance is 3.494, which gives ΔR = 0.24.

In PACE/EPB software, the following values should be inserted[3].

*Table 2: Encoding with an air layer*

| Layer | e[cm] | λ [W/mK] | R [m²K/W] |
|---|---|---|---|
| Bricks | 0.09 | 1.5 | 0.06 |
| Air layer | 0.05 | - | 0.09 |
| Cellular concrete | 0.15 | 0.20 | 0.75 |
| MW (continuous) | 0.05 | 0.035 | 1.428 |
| MW (in metallic profile) | 0.05 | 0.035 | 1.188* |
| OSB | 1 | 0.13 | 0.076 |
| Plaster | 1 | 0.2 | 0.05 |
| **TOTAL** | | | **3.642** |
| * value set manually from external calculation | | | |

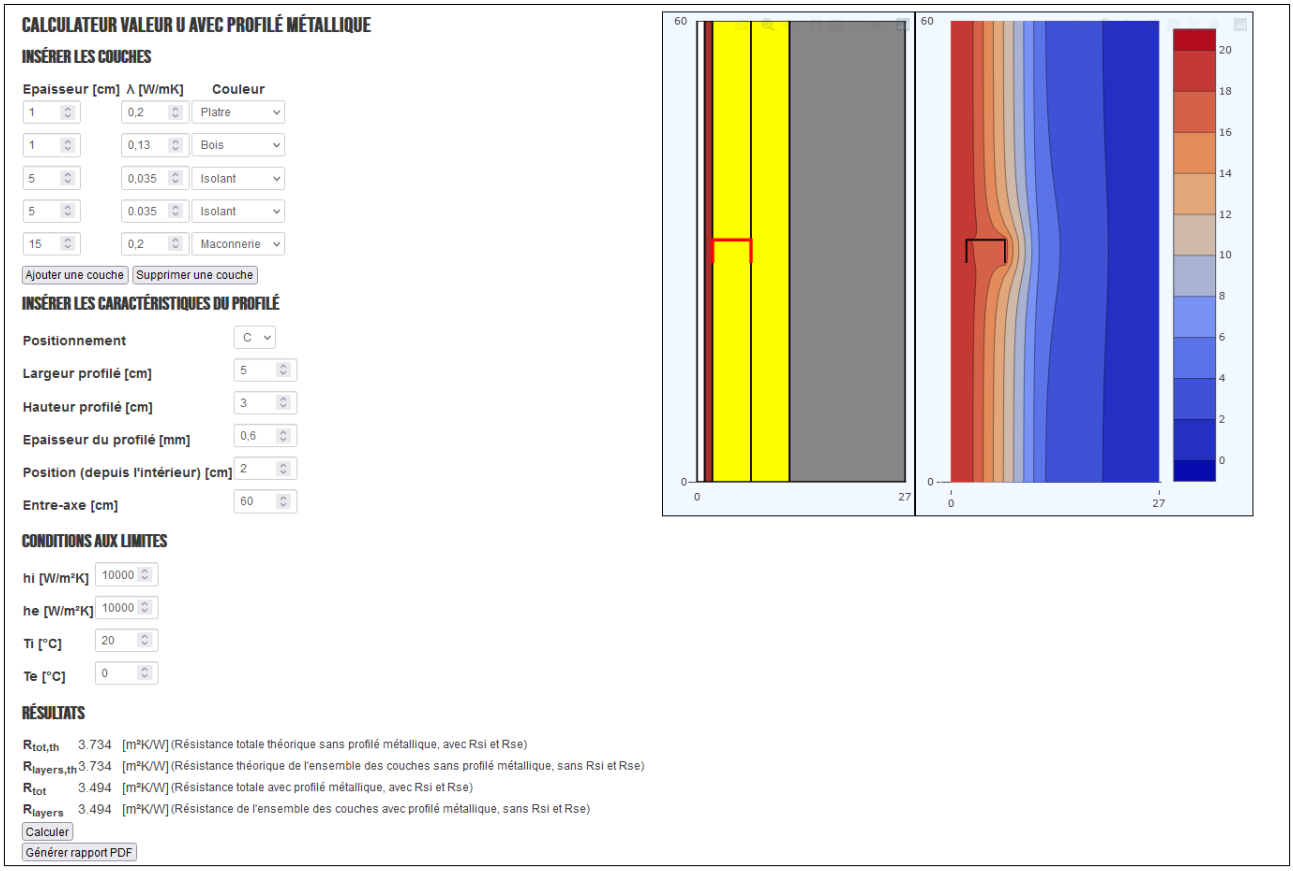



*Illustration 6: Use the calculator with air layers or heterogeneous layers*

3 Warning: resistance of air layers may not be the same in all software. The PACE value was used

## 4.4 What about $h_i/h_e$ and $R_{si}/R_{se}$?

$h_i$ and $h_e$ are respectively the internal and external convection coefficients. They are the inverse value of $R_{si}$ (= $1/h_i$) and $R_{se}$ (=$1/h_e$).

A default value of 10 is used for both $h_i$ and $h_e$ in the online calculator, but the values used in PACE or EPB may be different depending on the environment (outside or adjacent unheated space) and/ or construction type (not the same $R_{si}$ for roofs and walls).

Putting very high values of hi and he (e.g. 10000) is equivalent to set $R_{si} = R_{se} = 0$. These resistances have then to be added in EPB software or PACE.

These values can also be used to take into account other layers that are not explicitly modelled. For example, one could take into account the air layer and the facing brick of the previous example:

- $R_{\text{non represented layers}} = 0.09 + 0.06 = 0.15$ (R = 0.09 for the air layer, R = 0.06 for the brick)
- $h_e = 1/R_{\text{non represented layers}} = 6.67$

Setting he to 6.67 will take the air layer and the brick into account in the global calculation.

A calculation has been made with $h_i$ = 10000 and he = 6.67 (see Illustration 7). The value to look at is then "$R_{tot}$". The computed value is 3.644 m²K/W (nearly identical to 3.662 m²K/W computed in Table 2).

Note that in this computation, the true $R_{si}$ and $R_{se}$ are still not included. To take them also into account (in addition to the non-represented layers), we should use:

- hi = 10 (= $1/R_{si}$ = 1/0.1)
- he = $1/ (R_{se} + R_{\text{non-represented layers}})$ = 1/(0.1 + 0.15) = 4

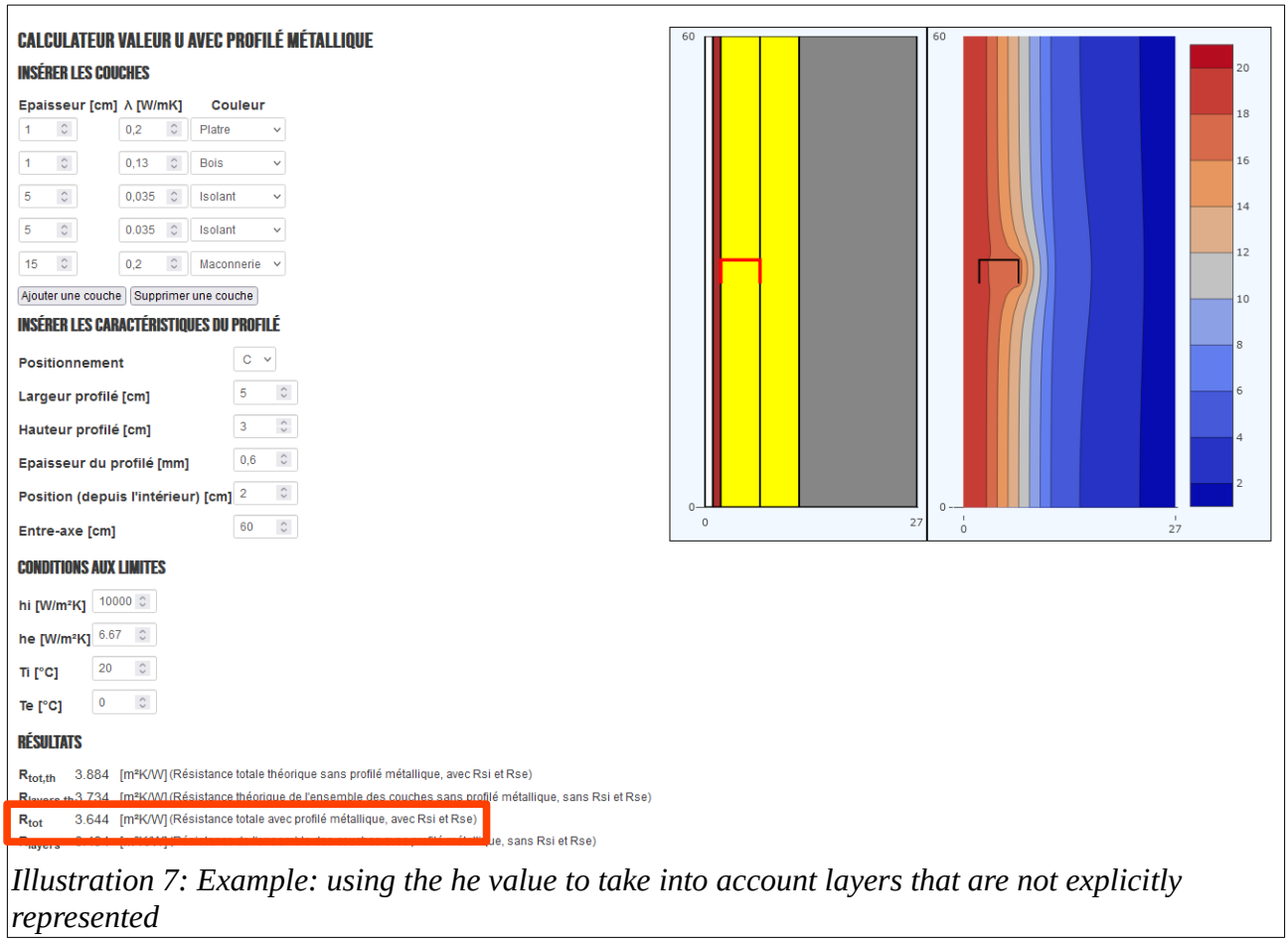



*Illustration 7: Example: using the he value to take into account layers that are not explicitly represented*