UNIVERSITÉ de Liège

Faculty of Applied Sciences
ArGEnCo Department (Architecture, Geology, Environment & Constructions) – Sector Arkhê (Architecture)
Laboratory of Architecture: Performances & Techniques (LAP&T)
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Université de Liège

Cold bridges on the building site of the European Bank of Investment at Luxemburg – Report 02

I the undersigned,

Jean-Marie HAUGLUSTAINE, civil engineer in architecture, doctor in applied sciences, Associate Professor at the ArGEnCo Department (Architecture, Geology, Environment and Construction) of the University of Liège, director of the Laboratory of Architecture: Performances & Techniques,

have been put in charge by the Joint venture CFE-VINCI, of assessing the cold bridges identified on the building site and of studying the ways to reduce their importance.

The present report is devoted to the eventual cold bridge caused by the structure that carries the smoke exhausts for the heated atriums.

This report includes this flyleaf and 36 pages of calculations and conclusions.

So written in LIEGE, the 15th of November, 2007,

J.-M. HAUGLUSTAINE.

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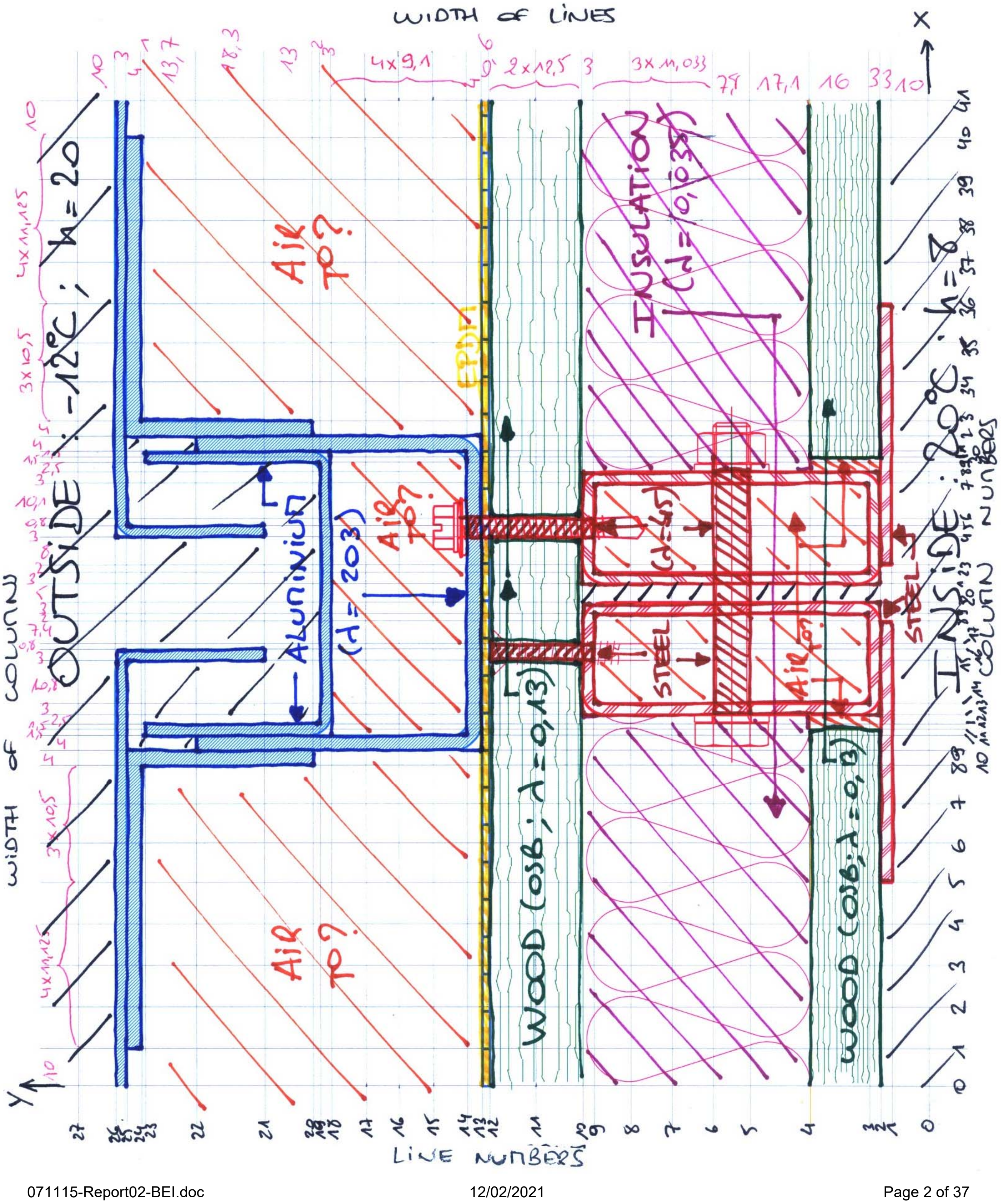
STUDY OF THERMAL BRIDGES – REPORT 02

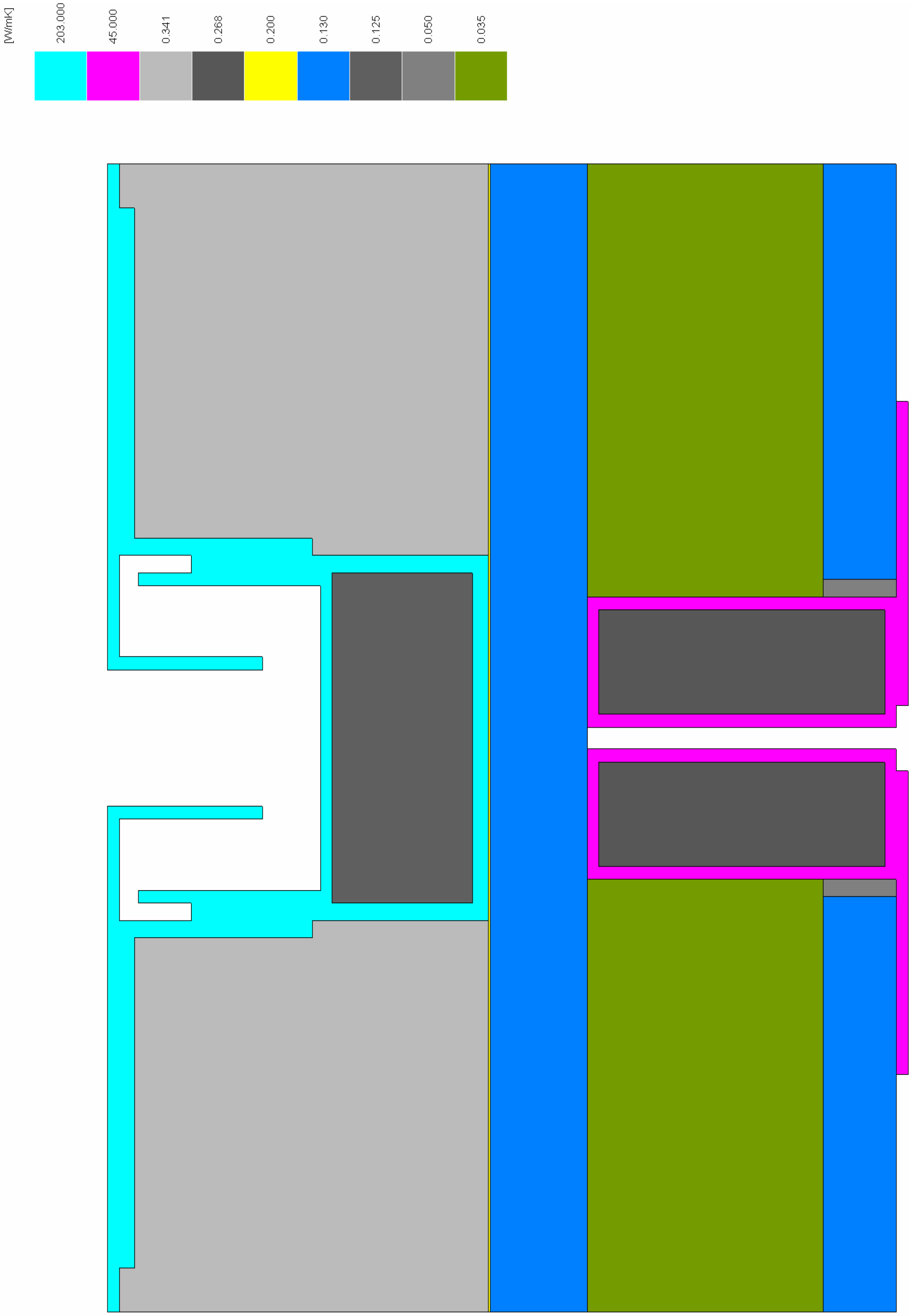
1. NODE – Smoke exhaust structure

1.1 Input data:

Vertical section (drawing)

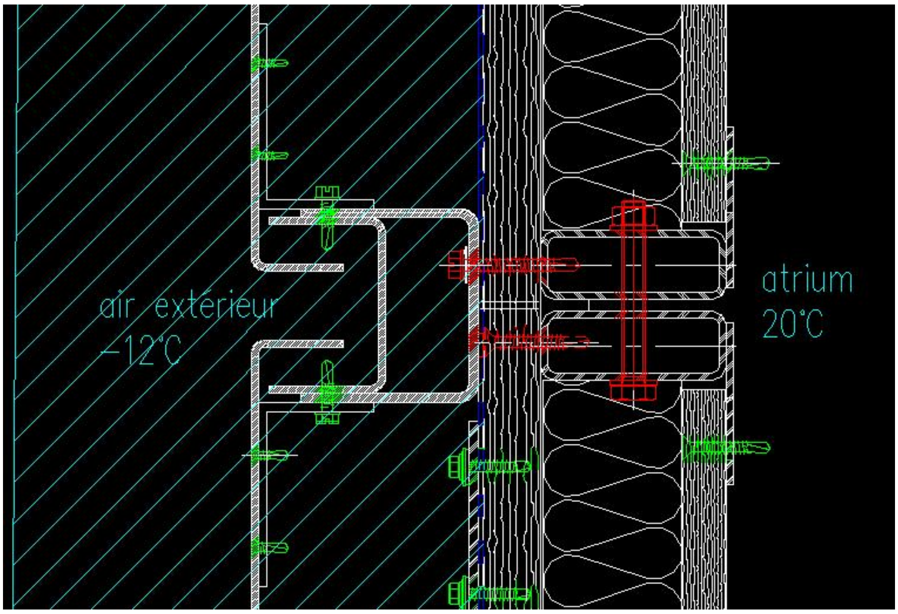


Vertical section (simulation)



Hypothesis:

- The fan is a technical product designed in order to not generate thermal bridges problems. The main concern about thermal bridges is located along the steel and aluminum structure: the aluminum is directly fixed to an OSB panel and to the steel structure by steel bolts (3 bolts/m). Those linked pieces, which are excellent thermal conductors (aluminum has a lambda value of 203 W/mK according to NBN B62-002 and steel of 45 W/mK) could create a thermal bridge.
- The modeling could have been a 2D analysis of the structure. But the point-shaped bolts need a 3D model to evaluate their influence.
- Trisco does not allow modeling a circular form, even less the cylinders of the bolts. Consequently, they will be modeled with a square section. Knowing that the heat transfer is a matter of external transfer area, the bolts will be modeled with the same external square perimeter that the initial external circle perimeter (so a side of the square will be equal to (pi*circle diameter)/4), which makes the small bolts with a 3.8 mm side and the big one with a 7.8 mm side.
- The green bolts in this picture don't link internal ambiance and to external conditions, so that they won't be taken into account in the model: their thermal influence can be neglected. But the three red bolts will be modeled, as their influence is a concern.



The three of them have been placed in the same section to create the worst situation.

- The structure contains cavities full of air. Trisco allows modeling them, by using a fictive material. When the direction of the heat flow is given (and so is the distance), Trisco calculates a fictive lambda value for the fictive material.
- The lambda values used in this model are all coming from the Trisco data base (from the Belgian standard NBN B62-002 or from the Physibel data base).
- The temperatures used are 20°C inside (h = 8), and -12°C outside (h = 20).

TRISCO - Input Data

TRISCO data file: smoke exhaust.trc

GRID of geometrical data

Grid unit = 0.001 m = 1 mm

No.	X	Y	Z	
0-1	10.000	10.000	100.000	
1-2	11.125	3.000	2.000	
2-3	11.125	3.000	3.800	small bolt
3-4	11.125	16.000	2.000	big bolt
4-5	11.125	17.100	24.610	
5-6	10.500	7.800	24.610	
6-7	10.500	11.033	24.610	
7-8	10.500	11.033	24.610	
8-9	4.000	11.033	24.610	
9-10	4.000	3.000	24.610	
10-11	1.500	12.500	24.610	
11-12	1.500	12.500	24.610	
12-13	2.500	0.600	24.610	
13-14	3.000	4.000	24.610	
14-15	10.800	9.100	24.610	
15-16	3.000	9.100	24.610	
16-17	0.800	9.100	24.610	
17-18	7.400	9.100	24.610	
18-19	2.000	3.000	24.610	
19-20	3.000	2.000	24.610	
20-21	5.000	13.000	24.610	
21-22	3.000	18.300	24.610	
22-23	2.000	13.700	24.610	
23-24	8.100	1.000	24.610	
24-25	3.000	4.000	2.000	
25-26	0.800	3.000	3.800	small bolt
26-27	10.100	10.000	2.000	big bolt
27-28	3.000		24.610	
28-29	2.500		24.610	
29-30	1.500		24.610	
30-31	1.500		24.610	
31-32	4.000		24.610	
32-33	4.000		24.610	
33-34	10.500		24.610	
34-35	10.500		24.610	
35-36	10.500		24.610	
36-37	11.125		24.610	
37-38	11.125		24.610	
38-39	11.125		24.610	
39-40	11.125		24.610	
40-41	10.000		24.610	
41-42			24.610	
42-43			24.610	
43-44			24.610	
44-45			24.610	
45-46			24.610	
46-47			24.610	
47-48			2.000	
48-49			3.800	small bolt
49-50			2.000	big bolt
50-51			100.000	
Sum	264.000	227.000	1207.800	

BLOCKS of geometrical data

No.	Col.	Xmin	Xmax	Ymin	Ymax	Zmin	Zmax
1	5	0	16	25	26	0	51
2	5	24	41	25	26	0	51
3	5	15	16	21	25	0	51
4	5	24	25	21	25	0	51
5	5	1	9	24	25	0	51
6	5	32	40	24	25	0	51
7	5	8	9	20	24	0	51
8	5	32	33	20	24	0	51
9	5	10	12	18	23	0	51
10	5	29	31	18	23	0	51
11	5	12	29	18	19	0	51
12	5	9	10	13	22	0	51
13	5	31	32	13	22	0	51
14	5	10	31	13	14	0	2
15	5	10	31	13	14	3	25
16	5	10	31	13	14	26	48
17	5	10	31	13	14	49	51
18	5	10	24	13	14	2	3
19	5	10	24	13	14	25	26
20	5	10	24	13	14	48	49
21	5	26	31	13	14	2	3
22	5	26	31	13	14	25	26
23	5	26	31	13	14	48	49
24	6	24	26	9	14	2	3
25	6	24	26	9	14	25	26
26	6	24	26	9	14	48	49
27	6	15	17	9	12	2	3
28	6	15	17	9	12	25	26
29	6	15	17	9	12	48	49
30	6	13	20	9	10	0	51
31	6	21	28	9	10	0	51
32	6	13	14	3	9	0	51
33	6	19	20	3	9	0	51
34	6	21	22	3	9	0	51
35	6	27	28	3	9	0	51
36	6	13	20	2	3	0	51
37	6	21	28	2	3	0	51
38	6	12	28	5	6	1	4
39	6	12	28	5	6	24	27
40	6	12	28	5	6	47	50
41	6	5	18	1	2	0	51
42	6	23	36	1	2	0	51
43	7	0	24	12	13	0	51
44	7	26	41	12	13	0	51
45	7	24	26	12	13	0	2
46	7	24	26	12	13	3	25
47	7	24	26	12	13	26	48
48	7	24	26	12	13	49	51
49	10	0	15	10	12	0	51
50	10	17	24	10	12	0	51
51	10	26	41	10	12	0	51
52	10	15	17	10	12	0	2
53	10	24	26	10	12	0	2
54	10	15	17	10	12	3	25
55	10	24	26	10	12	3	25
56	10	15	17	10	12	26	48
57	10	24	26	10	12	26	48
58	10	15	17	10	12	49	51

59	10	24	26	10	12	49	51
60	10	0	11	2	4	0	51
61	10	30	41	2	4	0	51
62	8	11	13	2	4	0	51
63	8	28	30	2	4	0	51
64	3	20	21	2	5	0	51
65	3	20	21	5	6	0	1
66	3	20	21	5	6	4	24
67	3	20	21	5	6	27	47
68	3	20	21	5	6	50	51
69	3	20	21	6	9	0	51
70	16	10	31	14	18	0	51
71	17	8	9	13	20	0	51
72	17	0	8	13	24	0	51
73	17	0	1	24	25	0	51
74	17	40	41	24	25	0	51
75	17	33	41	13	24	0	51
76	17	32	33	13	20	0	51
77	11	0	13	4	10	0	51
78	11	28	41	4	10	0	51
79	24	14	19	3	5	0	51
80	24	14	19	5	6	0	1
81	24	14	19	5	6	4	24
82	24	14	19	5	6	27	47
83	24	14	19	5	6	50	51
84	24	14	19	6	9	0	51
85	24	22	27	3	5	0	51
86	24	22	27	5	6	0	1
87	24	22	27	5	6	4	24
88	24	22	27	5	6	27	47
89	24	22	27	5	6	50	51
90	24	22	27	6	9	0	51
91	2	9	10	22	25	0	51
92	2	10	15	23	25	0	51
93	2	12	15	21	23	0	51
94	2	12	29	19	21	0	51
95	2	0	41	26	27	0	51
96	2	25	29	21	23	0	51
97	2	25	31	23	25	0	51
98	2	31	32	22	25	0	51
99	2	16	24	21	26	0	51
100	3	0	5	1	2	0	51
101	3	18	23	1	2	0	51
102	3	36	41	1	2	0	51
103	3	0	41	0	1	0	51

COLOURS of materials

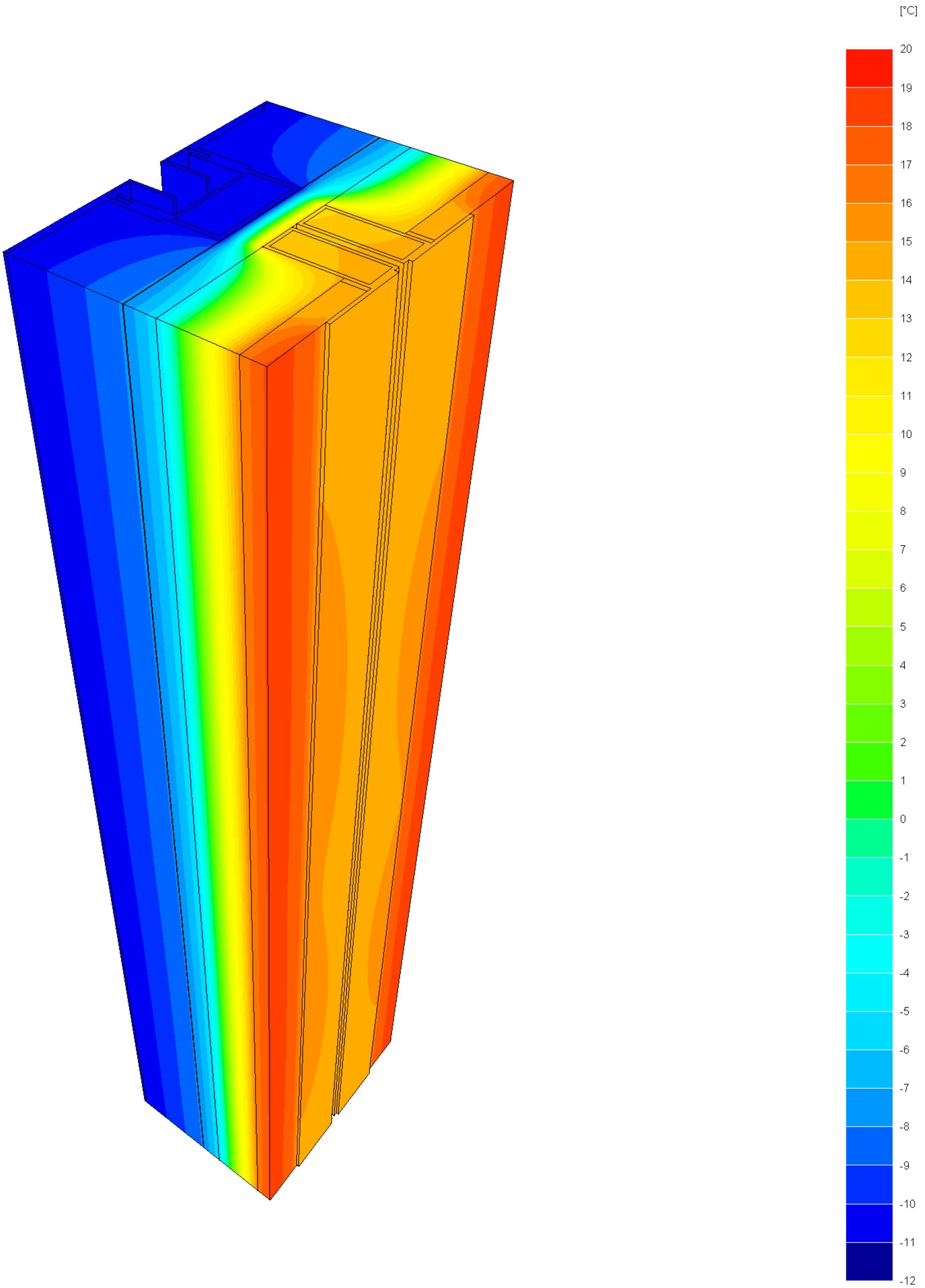
Col.	Type	CEN-rule	Name	lambda [W/mK]	eps [-]	t [°C]	h [W/m²K]	q [W/m²]
2	BC_SIMPL	NIHIL	EXTERIOR			-12.0	20.00	0
3	BC_SIMPL	NIHIL	INTERIOR			20.0	8.00	0
5	MATERIAL		aluminium 99%	203.000				
6	MATERIAL		steel	45.000				
7	MATERIAL		EPDM	0.200				
8	EQUIMAT	CEN_Yx_I		0.050				
10	MATERIAL		OSB panel	0.130				
11	MATERIAL		Polystyrène insul.	0.035				
16	EQUIMAT	CEN_Yx_I		0.125	EQUIMAT shows those air			
17	EQUIMAT	CEN_Yx_I		0.341	cavities, replaced by a			
24	EQUIMAT	CEN_Yx_I		0.268	fictive material			

Col.	ta [°C]	hc [W/m²K]	Pc [W]	tr [°C]	C1	C2	C3
2							
3							
8					0.025	0.73	0.333333
16					0.025	0.73	0.333333
17					0.025	0.73	0.333333
24					0.025	0.73	0.333333

Calculation parameters
Iteration cycles = 5
Maximum number of iterations (within each iteration cycle) = 10000
Maximum temperature difference (within each iteration cycle) = 0.0001°C
Maximum temperature difference (between iteration cycles) = 0.001°C
Heat flow divergence for total object = 0.001 %
Heat flow divergence for worst node = 1 %
Automatic recalculation of CEN-values
Default temperature difference across airspace = 10°C

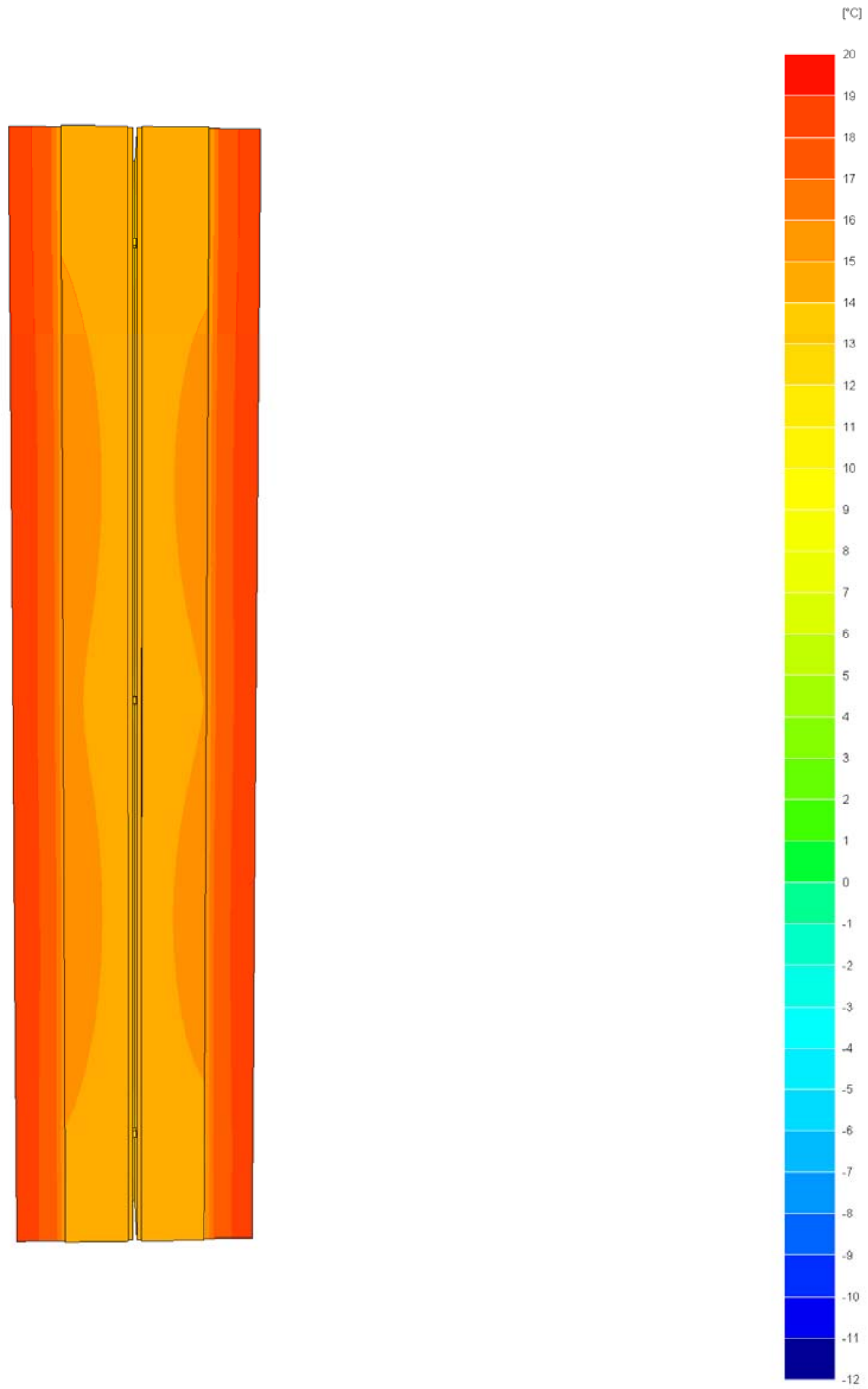
1.2 Graphical results:

General temperature in the model view



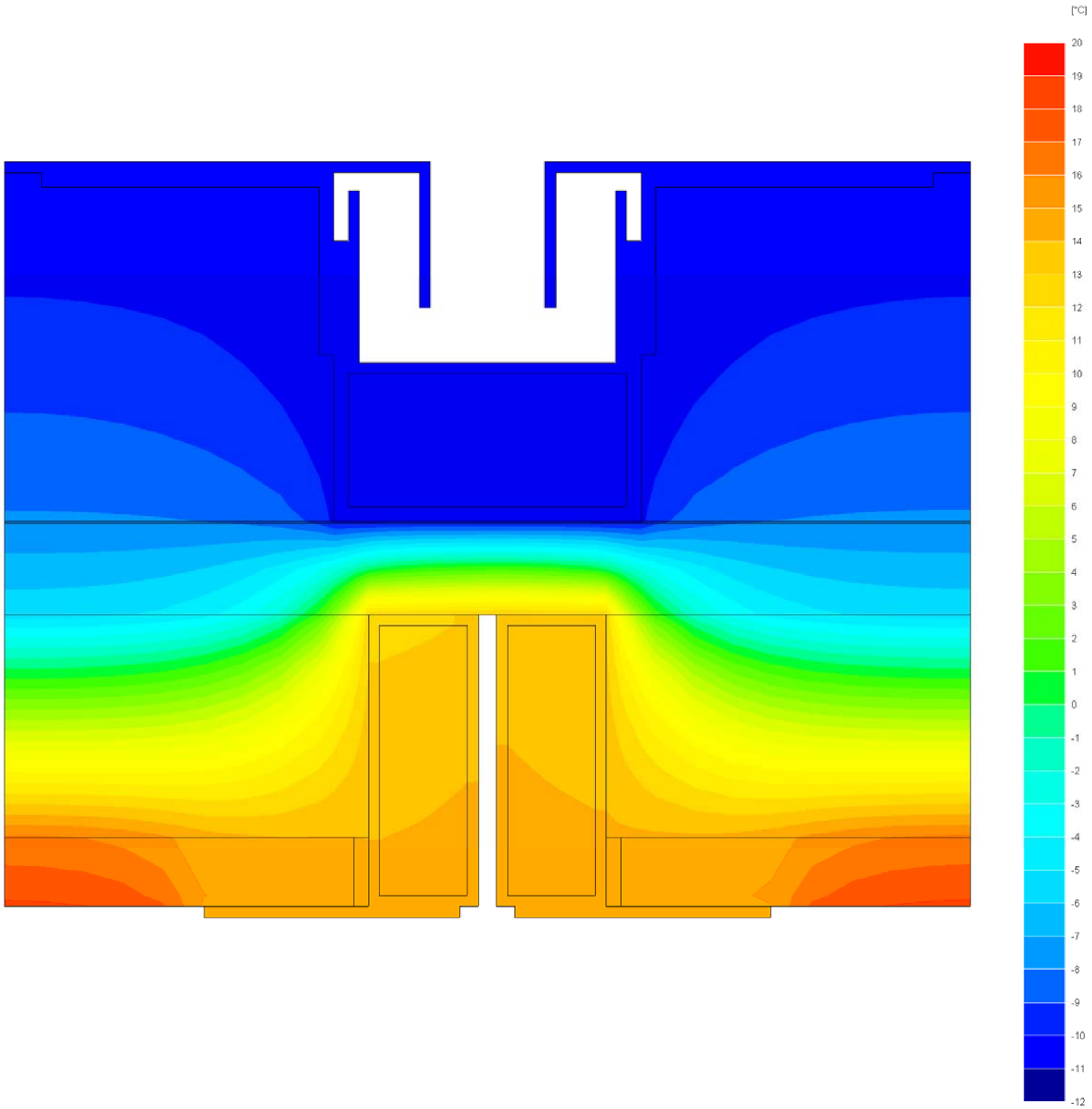
As expected, the aluminum and steel structures are the weakness in the thermal profile. Their high lambda value reflects the fact that they are excellent thermal conductors: the isothermal lines seem to get closer between those frames.

Inside temperature profile



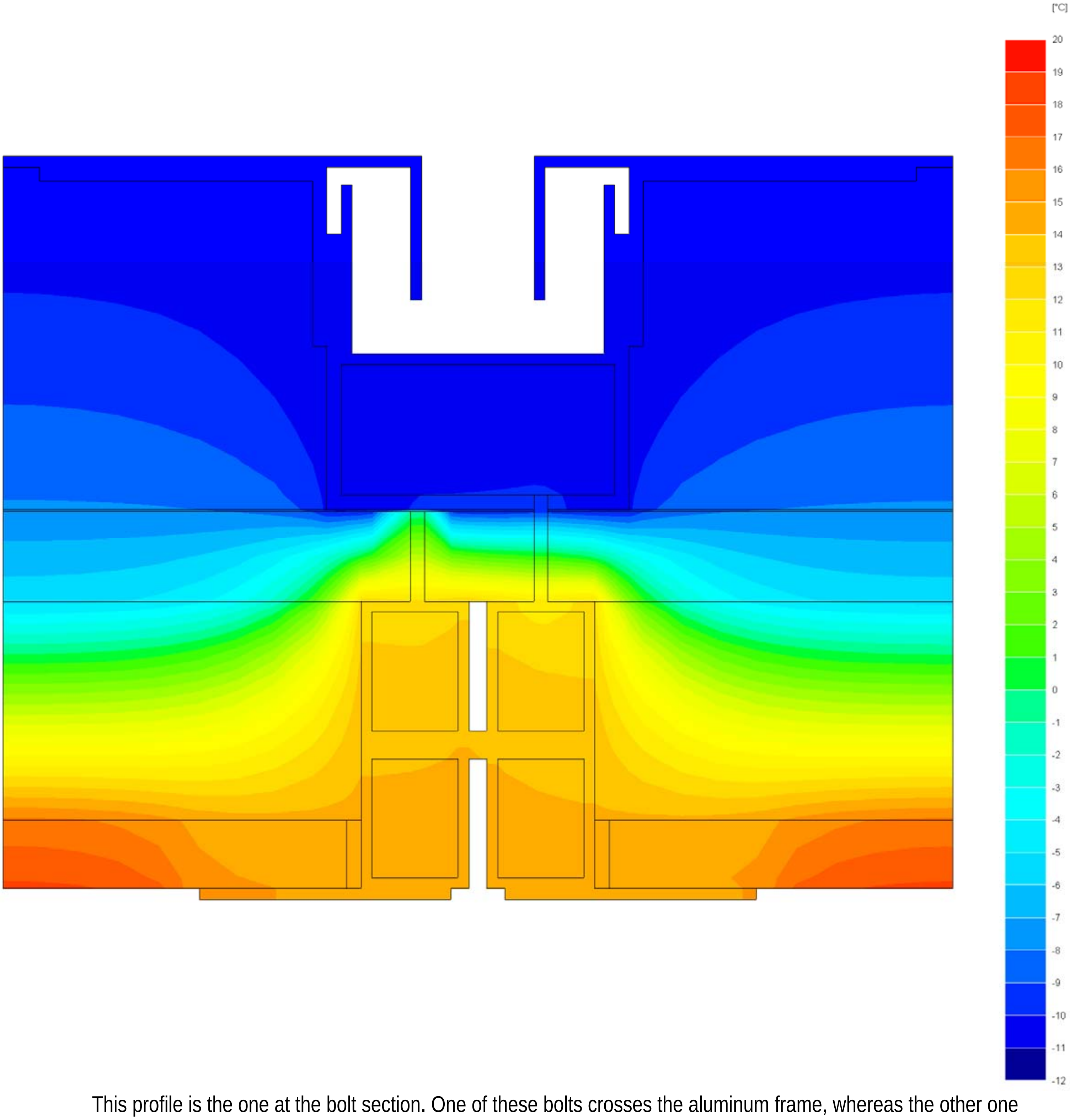
The temperature range we can notice is from 14 to 19°C. But we can find a lower temperature between the steel frames (about 12°C).

General temperature profile



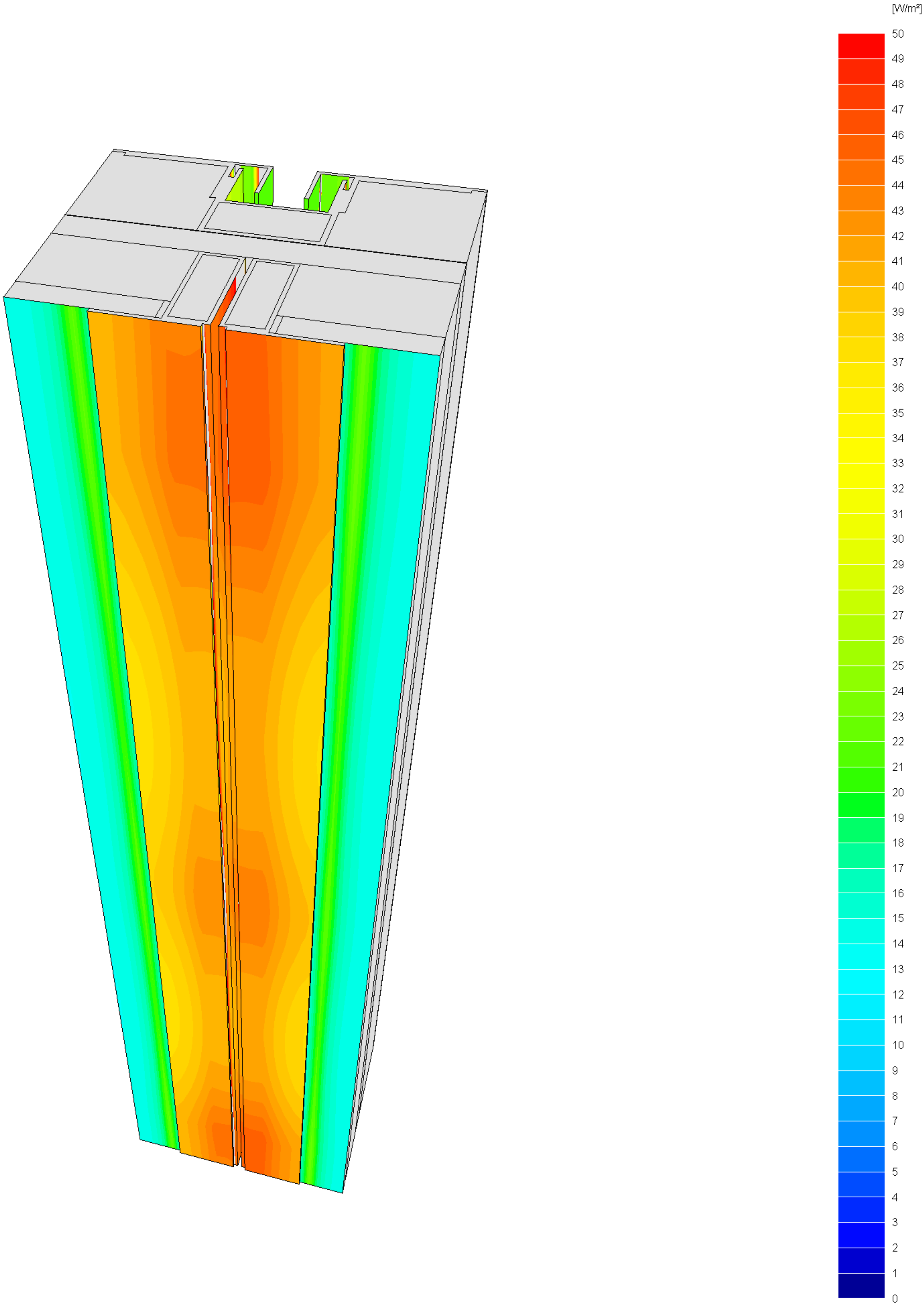
This first temperature profile is the one we can find almost all along the structure (where there is no bolt to break the symmetry). We can see that, for the temperatures given for boundary conditions, the symmetry is almost perfect, and the temperatures are spread in a range from – 11°C on the external face to 14°C to 19°C on the internal face.
The minimal inside temperature is about 12°C inside the small space between the steel frames.

Particular temperature profile



This profile is the one at the bolt section. One of these bolts crosses the aluminum frame, whereas the other one does not. This induces a small asymmetry on the profile.
The minimal inside temperature is a little bit higher than the 12°C encountered hereabove.

Heat fluxes on the inside face



1.5 Numerical results:

TRISCO - Calculation Results

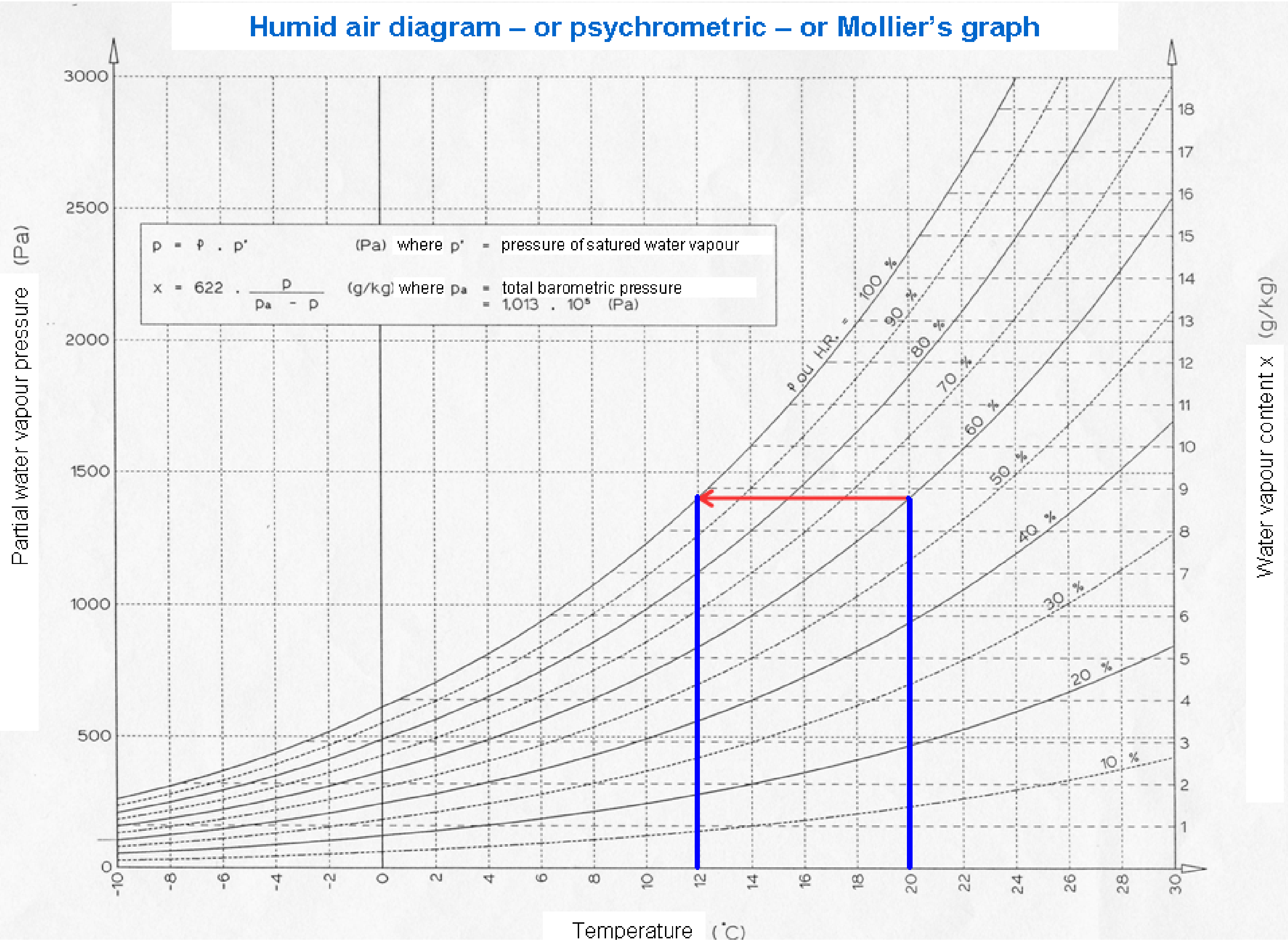
TRISCO data file: 1.trc

Number of nodes = 51688
Heat flow divergence for total object = 0.000695773
Heat flow divergence for worst node = 0.253891

Col.	Type	Name	tmin [°C]	X	Y	Z	tmax [°C]	X	Y	Z
2	BC_SIMPL	EXTERIOR	-11.00	16	21	15	-10.59	29	19	50
3	BC_SIMPL	INTERIOR	12.47	21	9	48	18.26	0	2	36
5	MATERIAL	aluminium 99%	-11.00	16	21	15	-9.83	25	13	25
6	MATERIAL	steel	-9.97	26	14	2	15.34	5	2	15
7	MATERIAL	EPDM	-10.40	9	13	15	-0.85	16	12	26
8	EQUIMAT		13.89	28	4	50	15.00	11	2	15
10	MATERIAL	OSB panel	-10.10	31	12	15	18.26	0	2	36
11	MATERIAL	Polystyrène insul.	-5.32	41	10	26	16.32	0	4	36
16	EQUIMAT		-10.71	20	18	15	-9.92	24	14	26
17	EQUIMAT		-10.89	0	25	15	-7.87	0	13	1
24	EQUIMAT		11.67	25	9	25	14.94	17	3	15

Col.	Type	Name	ta [°C]	Flow in [W]	Flow out [W]
2	BC_SIMPL	EXTERIOR		0.00	19.22
3	BC_SIMPL	INTERIOR		19.22	0.00

This temperature is the minimal inside temperature. It is just higher to the critical 12°C, where condensation can appear with 20°C ambient temperature and 60% relative humidity: see the Mollier's graph hereafter:



TRISCO - Temperatures in corner nodes

TRISCO data file: 1.trc

X	Y	Z	t [°C]
0	2	0	18.22
0	2	51	18.22
0	26	0	-10.84
0	26	51	-10.84
5	1	0	14.96
5	1	51	14.96
5	2	0	14.96
5	2	51	14.96
9	22	0	-10.70
9	22	51	-10.70
9	25	0	-10.80
9	25	51	-10.80
10	22	0	-10.70
10	22	51	-10.70
10	23	0	-10.71
10	23	51	-10.71
12	19	0	-10.61
12	19	51	-10.61
12	23	0	-10.71
12	23	51	-10.71
15	21	0	-10.95
15	21	51	-10.95
15	25	0	-10.89
15	25	51	-10.89
16	21	0	-10.95
16	21	51	-10.95
16	26	0	-10.89
16	26	51	-10.89
18	1	0	14.51
18	1	51	14.51
18	2	0	14.51
18	2	51	14.51
20	2	0	14.50
20	2	51	14.50
20	5	1	13.89
20	5	4	13.88
20	5	24	14.06
20	5	27	14.06
20	5	47	13.88
20	5	50	13.89
20	6	1	13.74
20	6	4	13.76
20	6	24	13.94
20	6	27	13.94
20	6	47	13.76
20	6	50	13.74
20	10	0	13.25
20	10	51	13.25
21	2	0	14.35
21	2	51	14.35
21	5	1	13.78
21	5	4	13.79
21	5	24	13.99
21	5	27	13.99

21	5	47	13.79	
21	5	50	13.78	
21	6	1	13.62	
21	6	4	13.66	
21	6	24	13.85	
21	6	27	13.85	
21	6	47	13.66	
21	6	50	13.62	
21	10	0	13.06	This is a low inside temperature. The 12.47°C
21	10	51	13.06	mentioned above is located at a non-node point, that
23	1	0	14.36	is the reason why it is not given in this list.
23	1	51	14.36	
23	2	0	14.36	
23	2	51	14.36	
24	21	0	-10.94	
24	21	51	-10.94	
24	26	0	-10.89	
24	26	51	-10.89	
25	21	0	-10.94	
25	21	51	-10.94	
25	25	0	-10.89	
25	25	51	-10.89	
29	19	0	-10.60	
29	19	51	-10.60	
29	23	0	-10.70	
29	23	51	-10.70	
31	22	0	-10.69	
31	22	51	-10.69	
31	23	0	-10.70	
31	23	51	-10.70	
32	22	0	-10.70	
32	22	51	-10.70	
32	25	0	-10.80	
32	25	51	-10.80	
36	1	0	14.83	
36	1	51	14.83	
36	2	0	14.83	
36	2	51	14.83	
41	2	0	18.21	
41	2	51	18.21	
41	26	0	-10.84	
41	26	51	-10.84	

2. NODE – Smoke exhaust structure: filling the gap between the steel frames with POM

2.1 Input data

Technical considerations on the product: (source: http://www.kern-gmbh.be/cgi-bin/riweta.cgi?nr=1201&lng=2)

polyoxymethylene copolymer extruded (POM-C E)

We use this material in the following process(es):

Extrusion.
Extruded profiles and semifinished products

Machined parts.
Lathed and milled parts in single and serial production

Material number		1201	
Density	ISO 1183	1,39	g/cm^3

Mechanical properties

Stress at yield	ISO 527	63	MPa
Elongation at break	ISO 527	31	%
Tensile modulus	ISO 527	2600	MPa
Ball pressure hardness	ISO 2039-1	135	MPa
Standard for ball pressure hardness		H358/30	
Hardness Shore (A/D) or Rockwell (R/L/M)	ISO 868, ISO 2039-2	D81	-
Izod notched impact strength at 23 °C	ISO 180/1A	7,0	KJ/m^2
Charpy notched impact strength at 23 °C	ISO 179/1eA	6	KJ/m^2

Electrical properties

Dielectric constant at 50 Hz	IEC 60250	3,8	-
Dielectric constant at 1 MHz	IEC 60250	3,8	-
Dissipation factor at 50 Hz	IEC 60250	10	1E-4
Dissipation factor at 1 MHz	IEC 60250	50	1E-4
Dielectric strength	IEC 60243-1	40	kV/mm
Thickness for electric strength		1,0	mm
Volume resistivity	IEC 60093	10^{14}	Ohm · m
Surface resistivity	IEC 60093	10^{14}	Ohm
Comparative tracking index	IEC 60112	600	-

Thermal properties

Thermal conductance	DIN 52 612	0,31	W/K m
Linear thermal expansion along|cross to direction of flow	ISO 11359	120	$10^{-6}/K$
Melting point or glass transition temp.	ISO 11357	166	°C
Heat distortion temperature A	ISO 75 HDT/A (1.8 MPa)	100	°C
Short time use temperature		140	°C
Continuous use temperature		90 [5)]	°C
Minimal use temperature		-50	°C

Other properties

Humidity absorption at 23°C/50%	ISO 62	0,20	%
Water absorption	ISO 62	0,65	%
Flammability UL 94	IEC 60695-11-10	HB	-
Thickness for UL 94		0,8	mm
Transparency (opaque/translucent/clear)		opaque	
Raw material		Ultraform H4320 (BASF)	

5) : Thermal ageing UL 746 (RTI) Mechanical W/O Imp., 40 000 h

Kern GmbH
Technische Kunststoffteile
Clemens-Kern-Straße 1
D-56276 Großmaischeid

The other input data are quite the same than in the previous model. The only changing data concerns the POM:

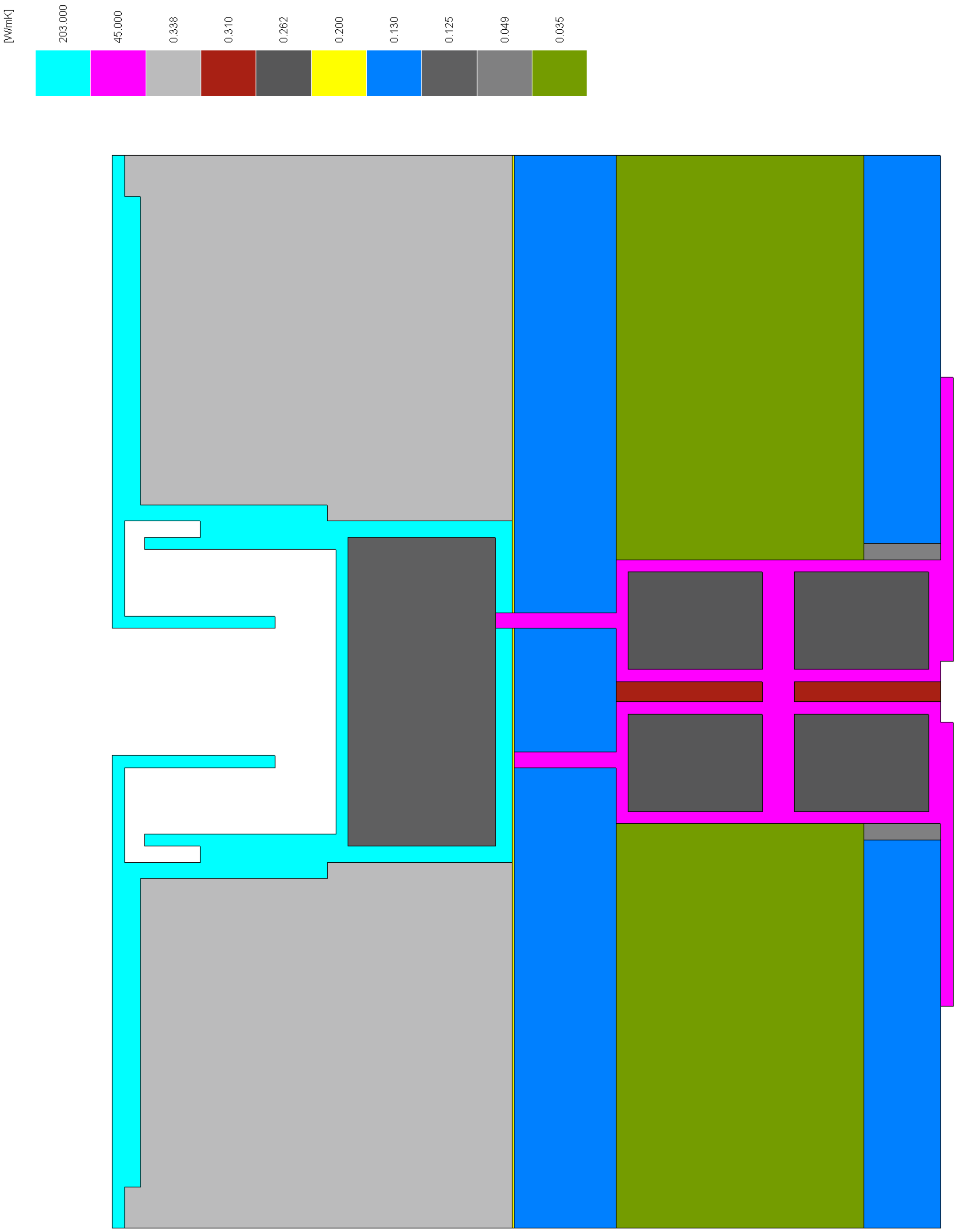
COLOURS of materials

Col.	Type	CEN-rule	Name	lambda [W/mK]	eps [-]	t [°C]	h [W/m²K]	q [W/m²]
2	BC_SIMPL	NIHIL	EXTERIOR			-12.0	20.00	0
3	BC_SIMPL	NIHIL	INTERIOR			20.0	8.00	0
5	MATERIAL		aluminium 99%	203.000				
6	MATERIAL		steel	45.000				
7	MATERIAL		EPDM	0.200				
10	MATERIAL		OSB panel	0.130				
11	MATERIAL		Polystyrène insul.	0.035				
12	MATERIAL		POM-C E	0.310				
16	EQUIMAT	CEN_Yx_I		0.125				
17	EQUIMAT	CEN_Yx_I		0.338				
24	EQUIMAT	CEN_Yx_I		0.262				

Col.	ta [°C]	hc [W/m²K]	Pc [W]	tr [°C]	C1	C2	C3
2							
3							
16					0.025	0.73	0.333333
17					0.025	0.73	0.333333
24					0.025	0.73	0.333333

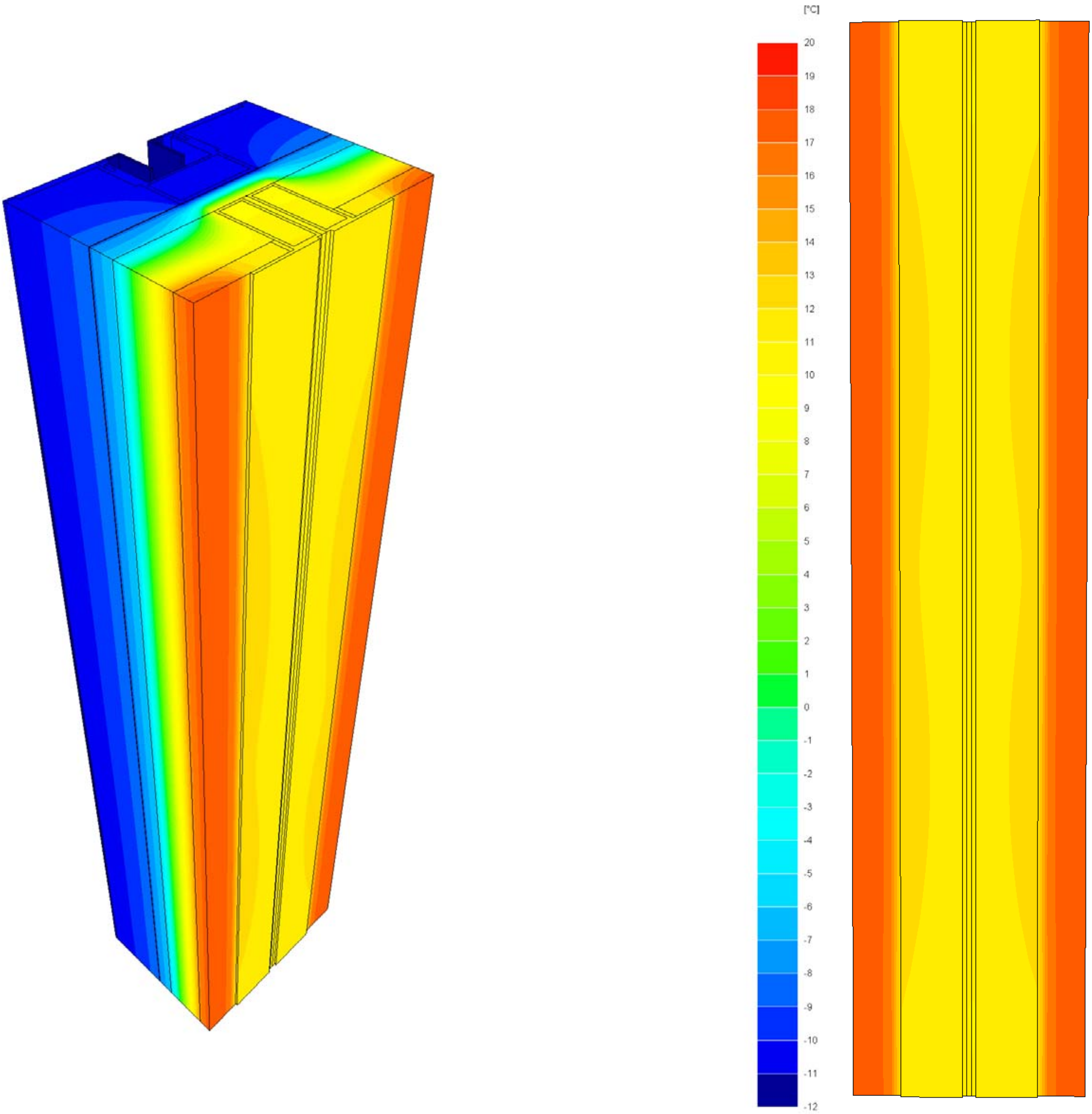
Vertical section (simulation)

The picture hereafter shows the vertical section as modeled, with the POM material inserted in that gap (in dark red). Its lambda value is 0.31 W/mK as given in the documentation.



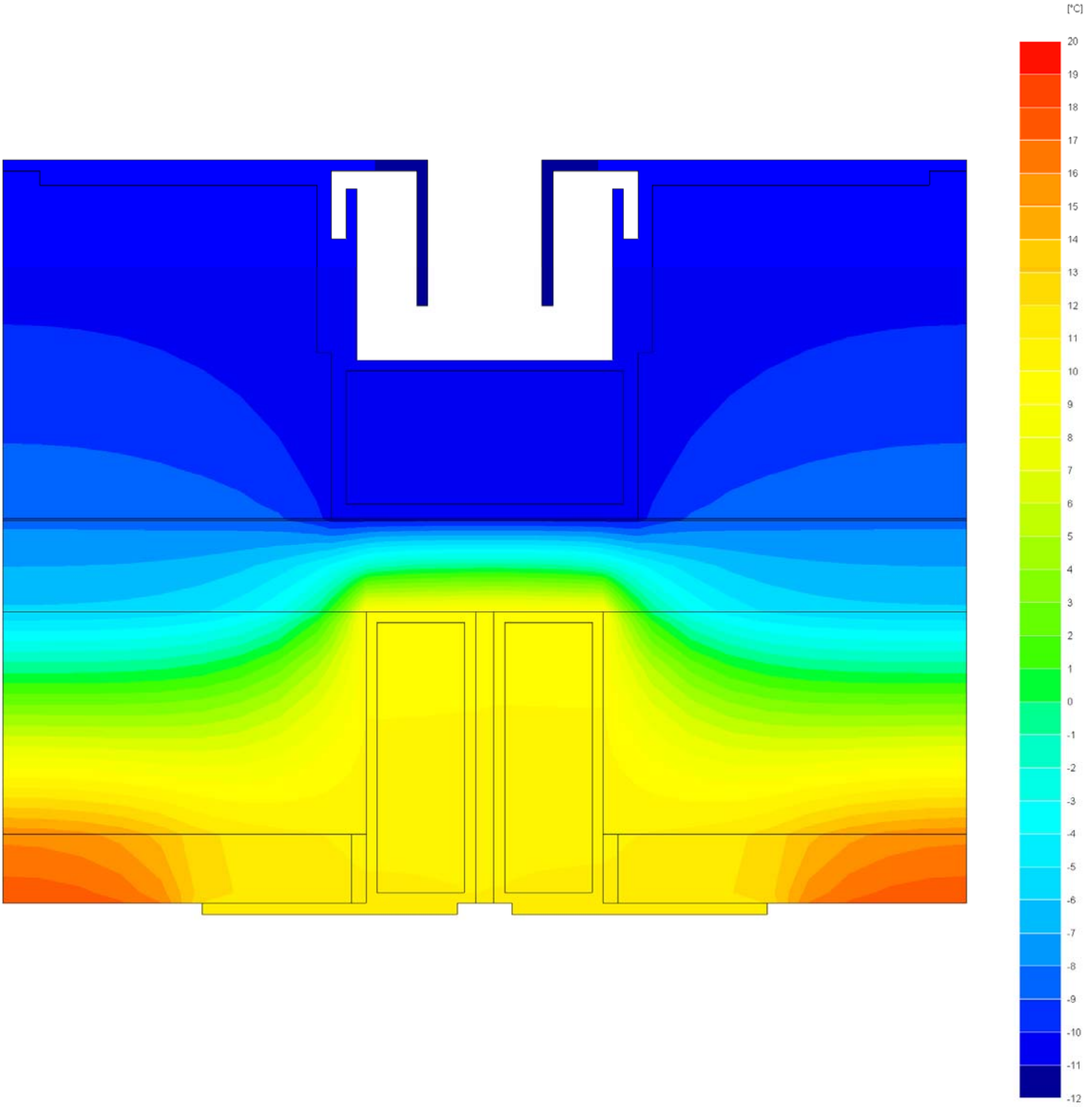
2.2 Graphical results:

Global temperature profile in the model and temperatures on the inside face



At first sight, the results don't seem to be getting better with the new material.

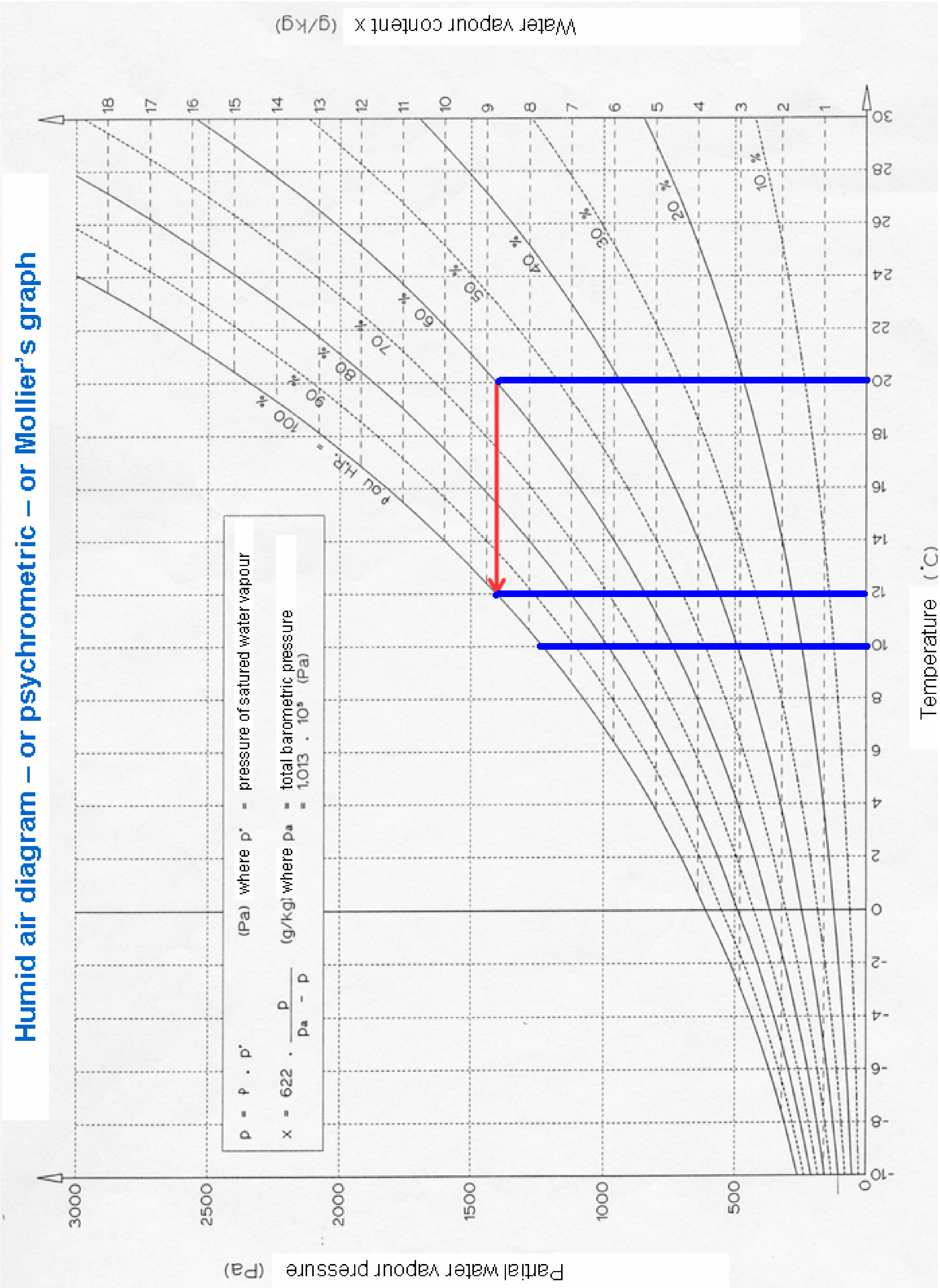
General temperature profile



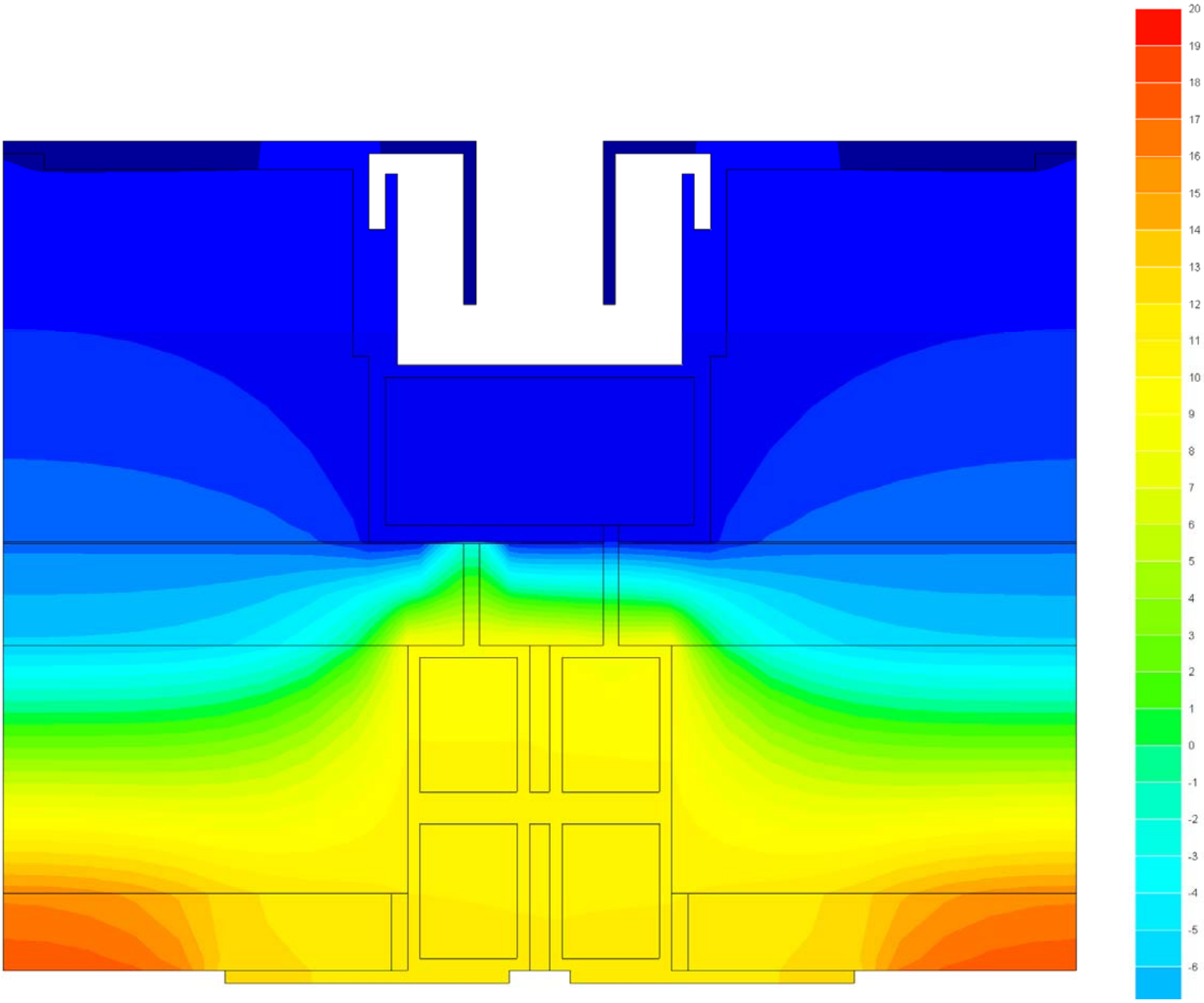
We can see that the results are even getting worse with that additional material filling the gap. The reason seems quite simple: in the previous model, that space used to be filled with 20°C air (h=8). Now, it is filled with a material surrounded by steel at a lower temperature: the POM will get to this temperature, and bring those results: the temperature of the inside faces of the model are lower than in the previous basic model, going from 10 to 17°C (instead of 14 to 18°C).

Mollier's graph

It shows that if the inside ambiance is 20°C and 60% relative humidity, 12°C could be accepted, but 10°C is much too low to prevent condensation.



Particular temperature profile



This profile at bolts section confirms what has been said previously: the presence of the POM reduces the minimal inside temperature, from 14°C to about 10°C.

2.3 Numerical results

```
TRISCO - Calculation Results

TRISCO data file: with POM.trc

Number of nodes = 51688
Heat flow divergence for total object = 8.98145e-005
Heat flow divergence for worst node = 0.220848
```

Col.	Type	Name	tmin [°C]	X	Y	Z	tmax [°C]	X	Y	Z
2	BC_SIMPL	EXTERIOR	-11.12	16	21	36	-10.77	29	19	1
3	BC_SIMPL	INTERIOR	10.97	21	2	50	17.95	0	2	15
5	MATERIAL	aluminium 99%	-11.12	16	21	36	-10.11	25	13	25
6	MATERIAL	steel	-10.24	26	14	49	12.43	5	2	15
7	MATERIAL	EPDM	-10.60	9	13	37	-2.39	16	12	25
10	MATERIAL	OSB panel	-10.35	10	12	37	17.95	0	2	15
11	MATERIAL	Polystyrène insul.	-5.83	41	10	50	15.76	0	4	15
12	MATERIAL	POM-C E	8.99	21	10	48	11.83	11	2	15
16	EQUIMAT		-10.88	20	18	36	-10.19	24	14	25
17	EQUIMAT		-11.03	0	25	36	-8.26	0	13	1
24	EQUIMAT		8.47	25	9	48	11.68	14	3	15

Col.	Type	Name	ta [°C]	Flow in [W]	Flow out [W]
2	BC_SIMPL	EXTERIOR		0.00	16.74
3	BC_SIMPL	INTERIOR		16.74	0.00

The minimal inside temperature is in fact about 11°C, which is still too low to be admitted.
Nevertheless, we can notice that the heat flow going through the model is quite inferior to the one obtained in the basic solution (16.74 W instead of 19.22 W), but the difference is small (2.48 W).

TRISCO - Temperatures in corner nodes

TRISCO data file: with POM.trc

X	Y	Z	t [°C]
0	2	0	17.91
0	2	51	17.91
0	26	0	-10.99
0	26	51	-10.99
5	1	0	12.00
5	1	51	12.00
5	2	0	12.00
5	2	51	12.00
9	22	0	-10.87
9	22	51	-10.87
9	25	0	-10.96
9	25	51	-10.96
10	22	0	-10.87
10	22	51	-10.87
10	23	0	-10.88
10	23	51	-10.88
12	19	0	-10.79
12	19	51	-10.79
12	23	0	-10.88
12	23	51	-10.88
15	21	0	-11.08
15	21	51	-11.08
15	25	0	-11.04
15	25	51	-11.04
16	21	0	-11.08
16	21	51	-11.08
16	26	0	-11.04
16	26	51	-11.04
18	1	0	11.11
18	1	51	11.11
18	2	0	11.09

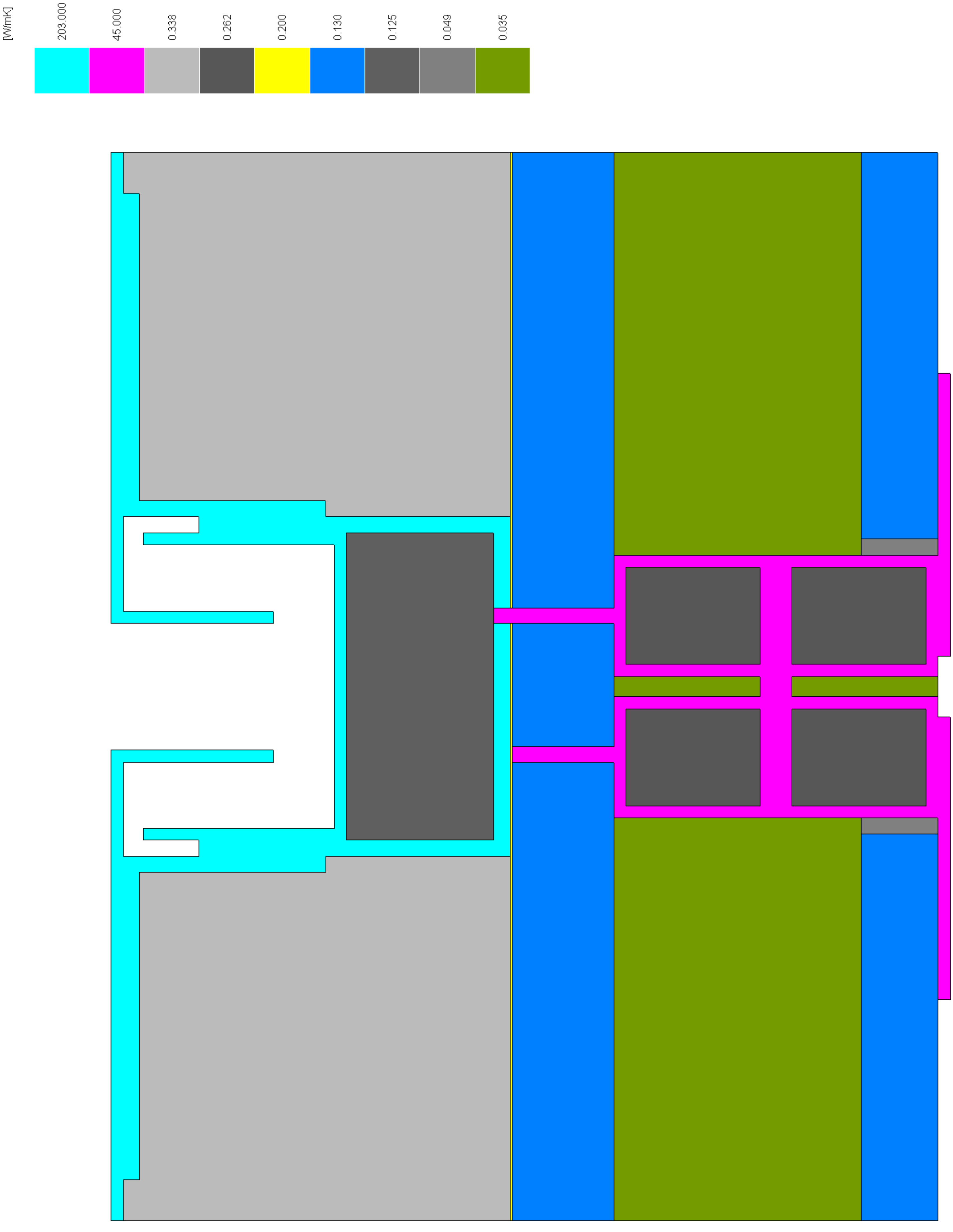
18	2	51	11.09
23	1	0	11.07
23	1	51	11.07
23	2	0	11.06
23	2	51	11.06
24	21	0	-11.08
24	21	51	-11.08
24	26	0	-11.04
24	26	51	-11.04
25	21	0	-11.08
25	21	51	-11.08
25	25	0	-11.04
25	25	51	-11.04
29	19	0	-10.78
29	19	51	-10.78
29	23	0	-10.87
29	23	51	-10.87
31	22	0	-10.86
31	22	51	-10.86
31	23	0	-10.87
31	23	51	-10.87
32	22	0	-10.87
32	22	51	-10.87
32	25	0	-10.95
32	25	51	-10.95
36	1	0	11.96
36	1	51	11.96
36	2	0	11.96
36	2	51	11.96
41	2	0	17.91
41	2	51	17.91
41	26	0	-10.99
41	26	51	-10.99

3. NODE – Smoke exhaust structure: filling the gap between the steel frames with Rockwool insulation

3.1 Input data

Another possible solution is to fill the same gap between the two steel frames by the same insulation that is used between the two wooden panels. Even if its thermal conductance is about ten times lower (0.035) than the POM's lambda value (0.31), we believe that the results won't necessarily get better as far as the inside temperatures are concerned, for the same reasons as given for the POM solution.

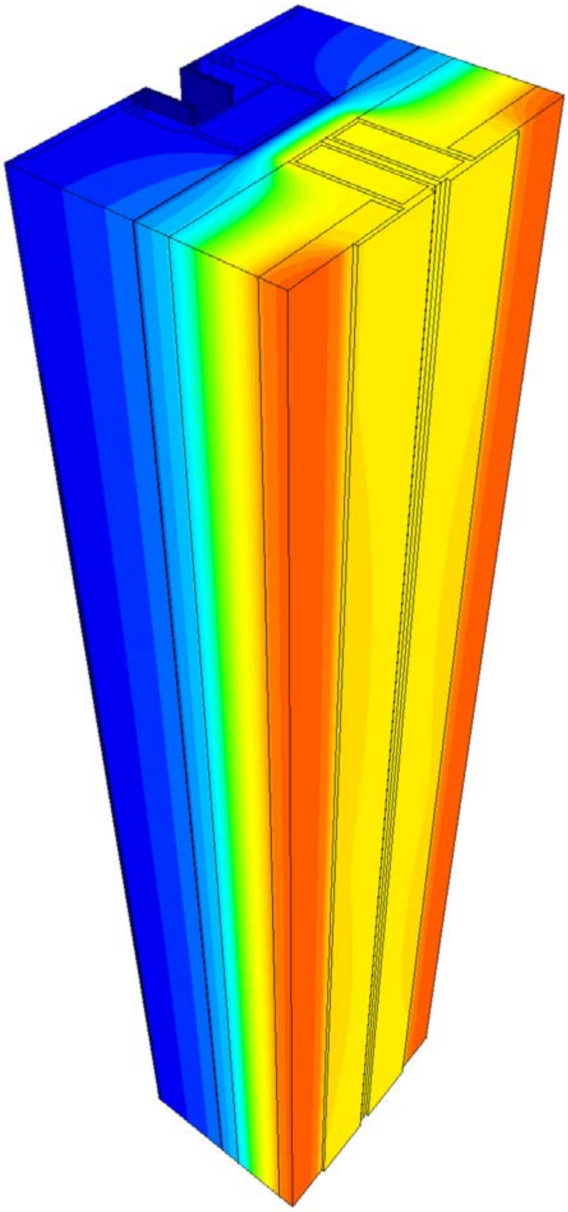
Vertical section (simulation)

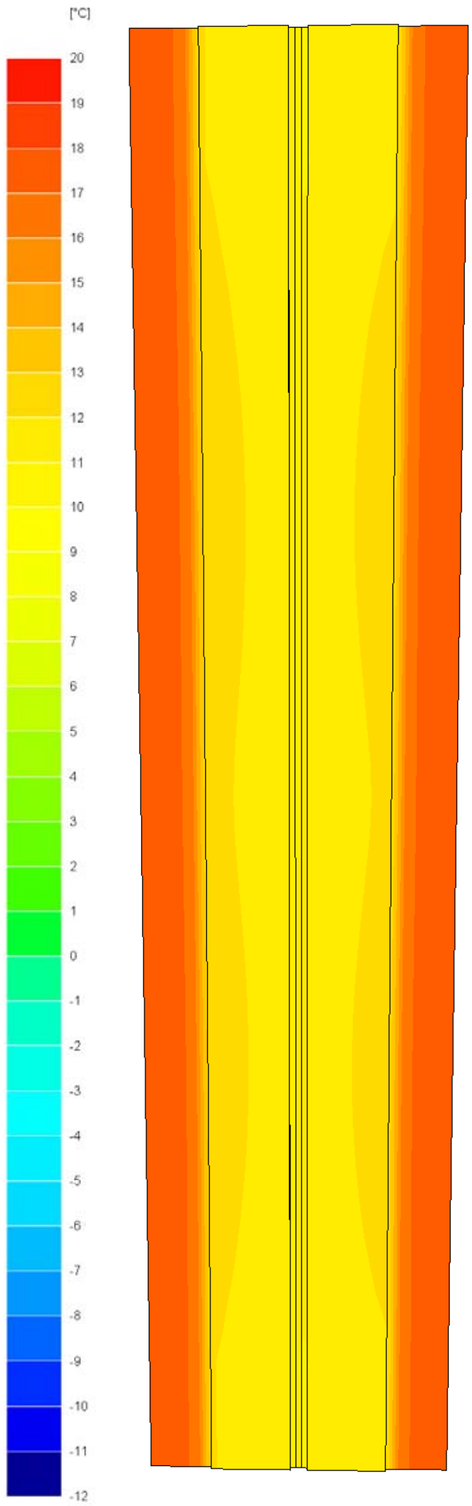


3.2 Graphical results

Global temperature profile in the model and temperature on the internal face

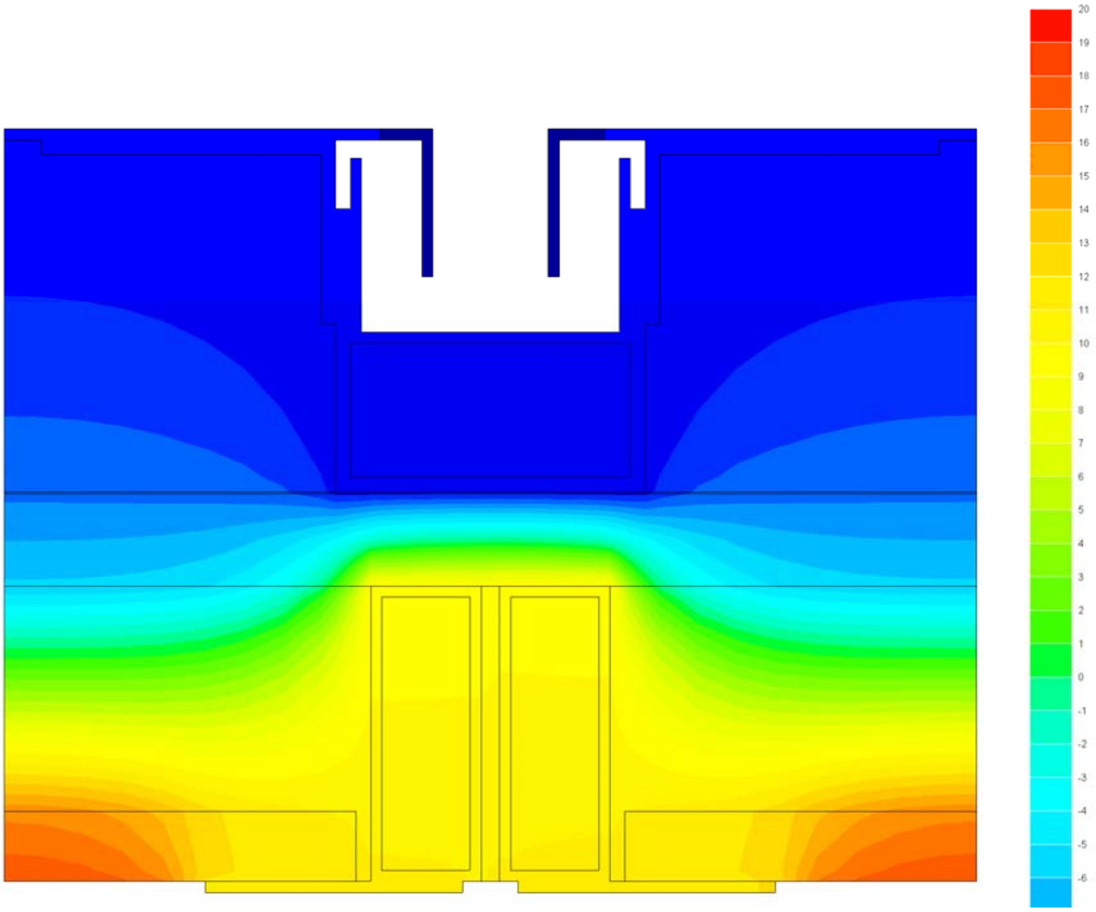
As expected, the results are the same than the ones we got in the POM solution:



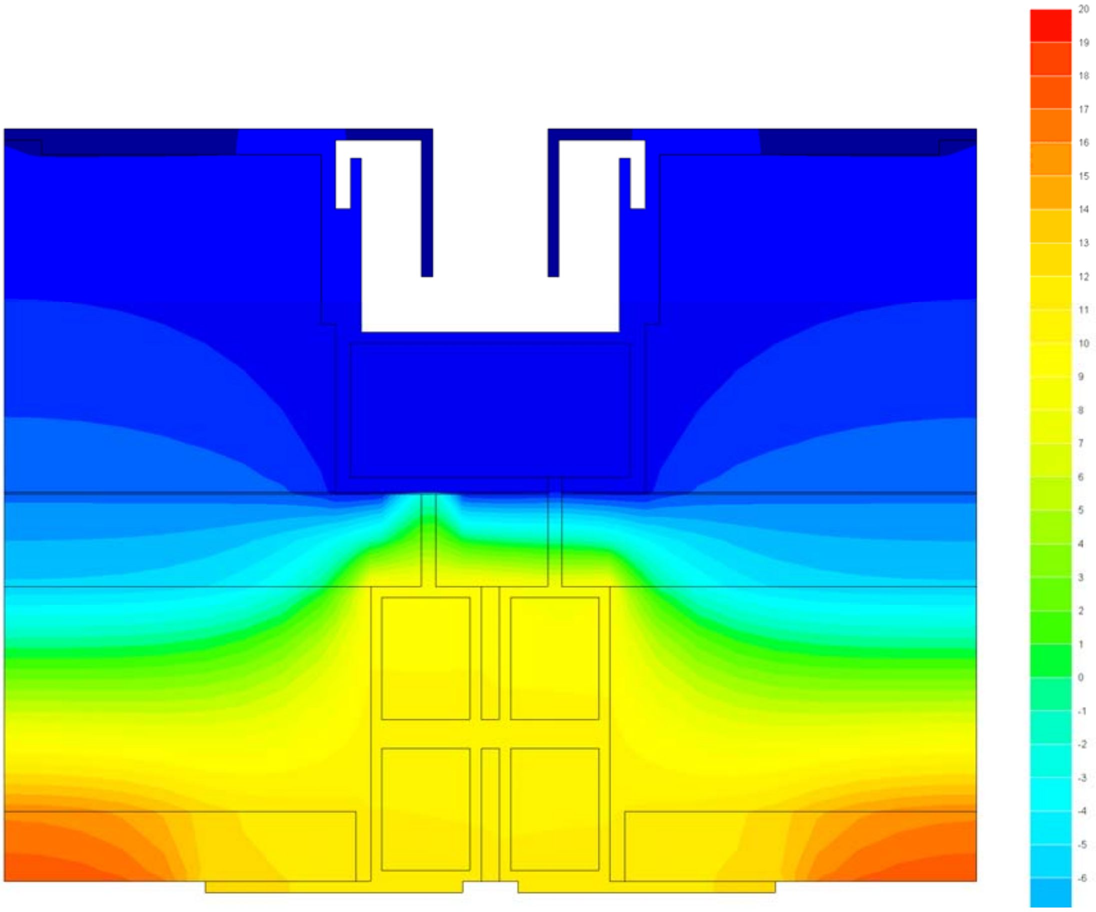


These pictures seem exactly like the one given in the POM solution.

General temperature profile



Particular temperature profile (bolts section)



The conclusions we can obtain from these pictures are the exact same than in the POM solution.

3.3 Numerical results

TRISCO - Calculation Results

TRISCO data file: with rockwool.trc

Number of nodes = 51688
Heat flow divergence for total object = 0.000437672
Heat flow divergence for worst node = 0.182175

Col.	Type	Name	tmin [°C]	X	Y	Z	tmax [°C]	X	Y	Z
2	BC_SIMPL	EXTERIOR	-11.12	15	21	15	-10.77	29	19	50
3	BC_SIMPL	INTERIOR	10.94	21	2	50	17.96	0	2	36
5	MATERIAL	aluminium 99%	-11.12	15	21	15	-10.12	25	13	25
6	MATERIAL	steel	-10.24	26	14	2	12.45	5	2	15
7	MATERIAL	EPDM	-10.60	9	13	14	-2.38	16	12	25
10	MATERIAL	OSB panel	-10.35	31	12	14	17.96	0	2	36
11	MATERIAL	Polystyrène insul.	-5.83	41	10	1	15.77	0	4	36
16	EQUIMAT		-10.88	20	18	15	-10.19	24	14	26
17	EQUIMAT		-11.03	0	25	15	-8.25	0	13	50
24	EQUIMAT		8.42	25	9	48	11.70	14	3	15

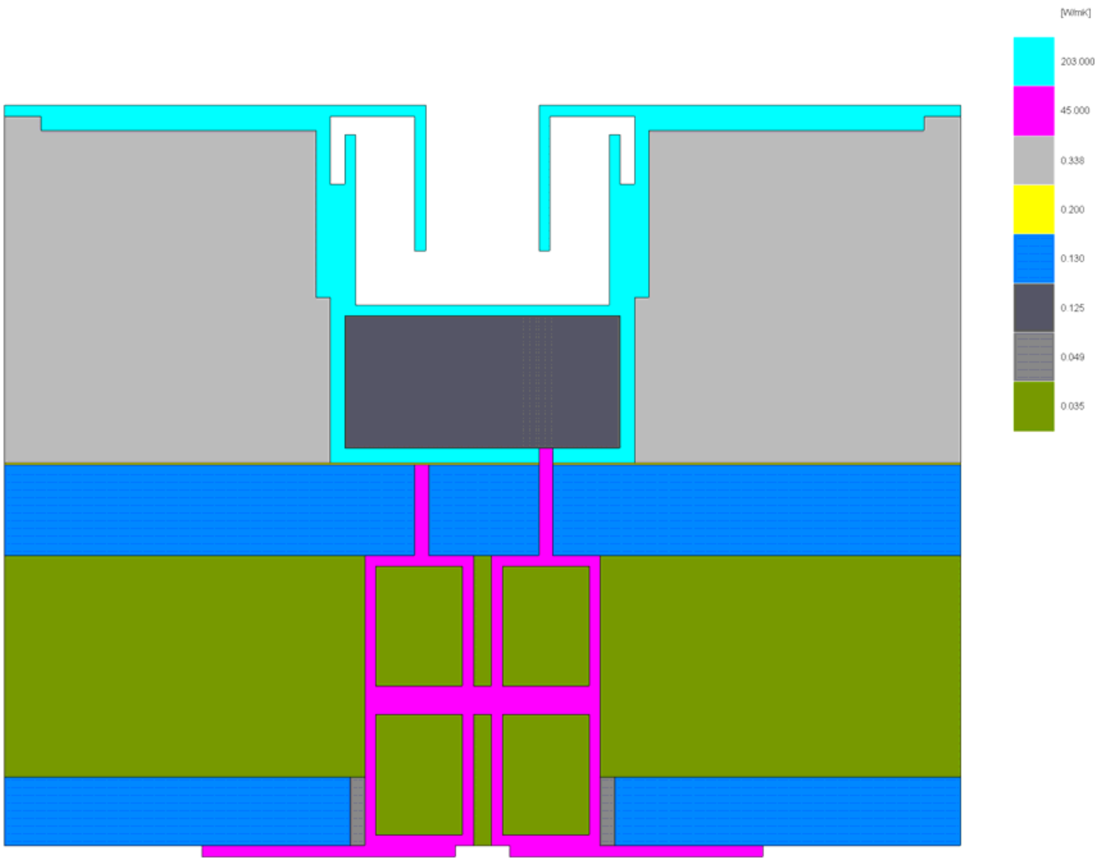
Col.	Type	Name	ta [°C]	Flow in [W]	Flow out [W]
2	BC_SIMPL	EXTERIOR		0.00	16.74
3	BC_SIMPL	INTERIOR		16.74	0.00

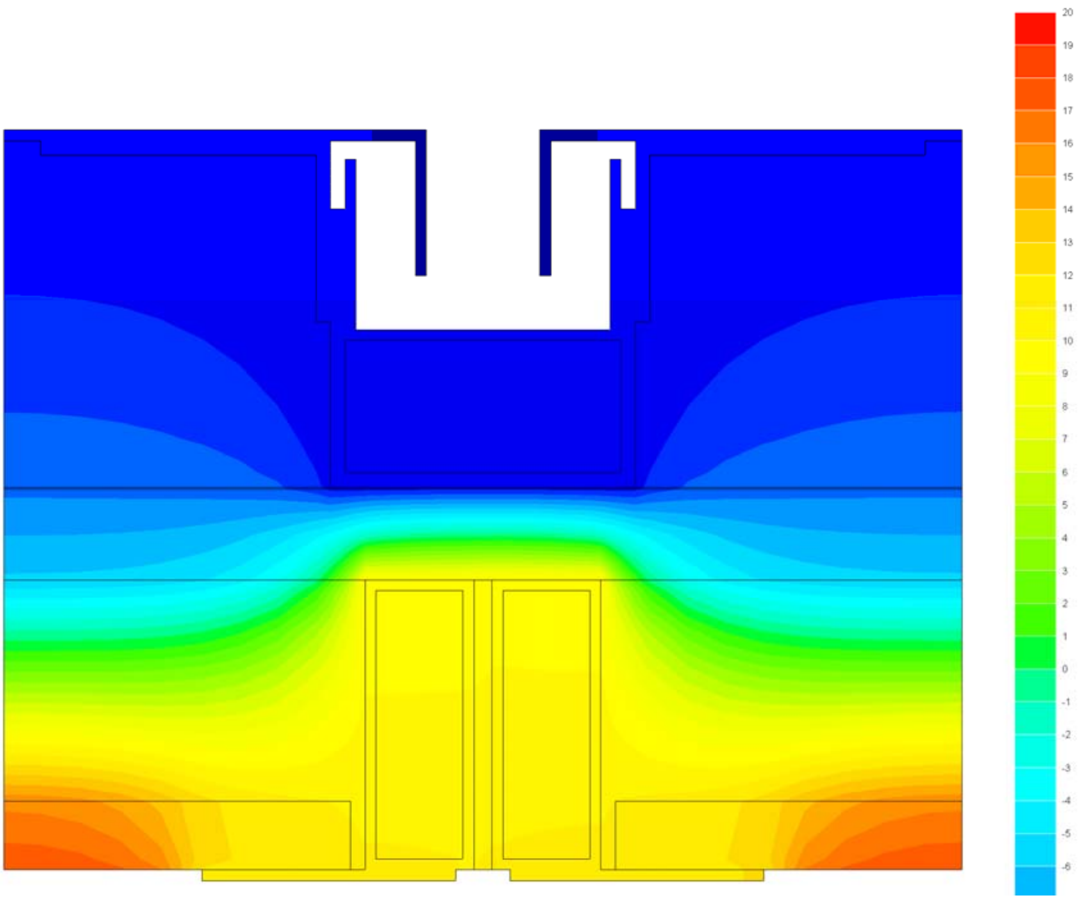
The minimal inside temperature is here again about 11°C, which is still too low.
The heat flow is the same than in the POM solution (16.74 W).

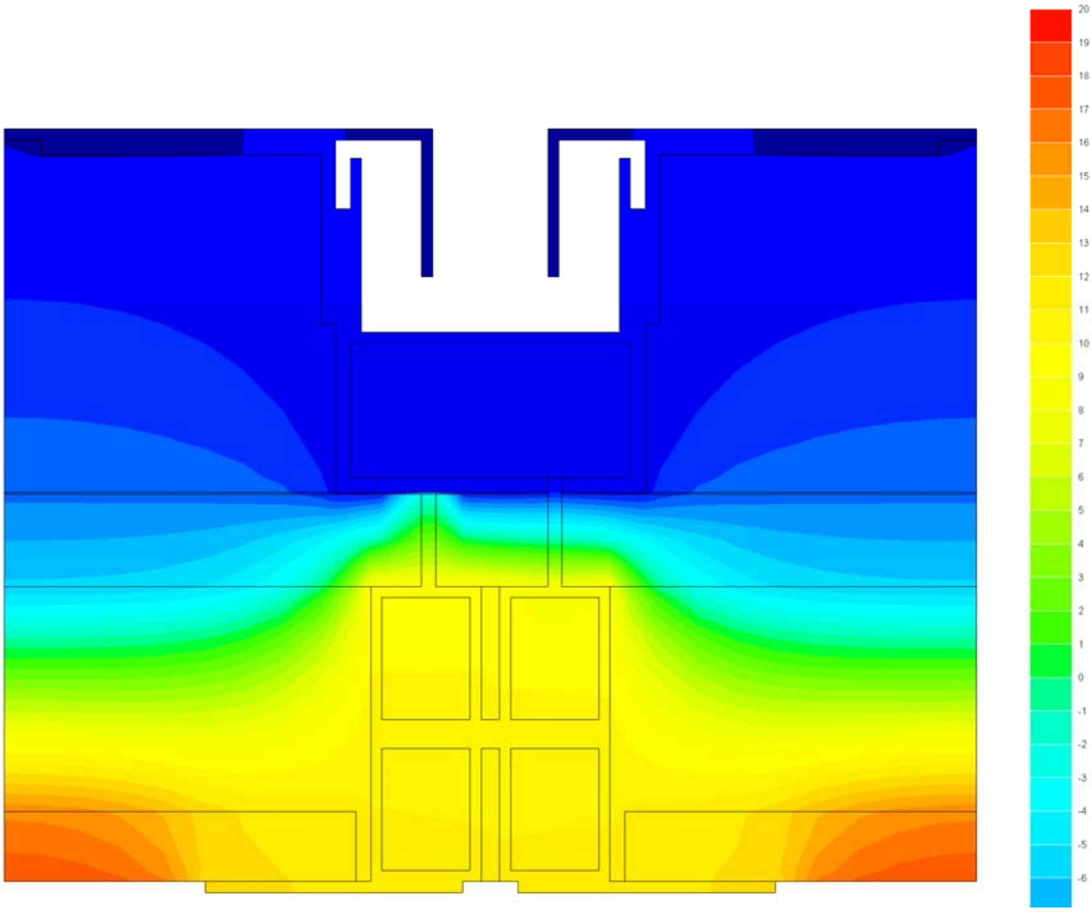
4. NODE – Smoke exhaust structure: filling the gaps with Rockwool insulation

Here are some other insulation-filling solutions:

1. Filling the steel frames:







TRISCO - Calculation Results

TRISCO data file: with insulation in the steel frames.trc

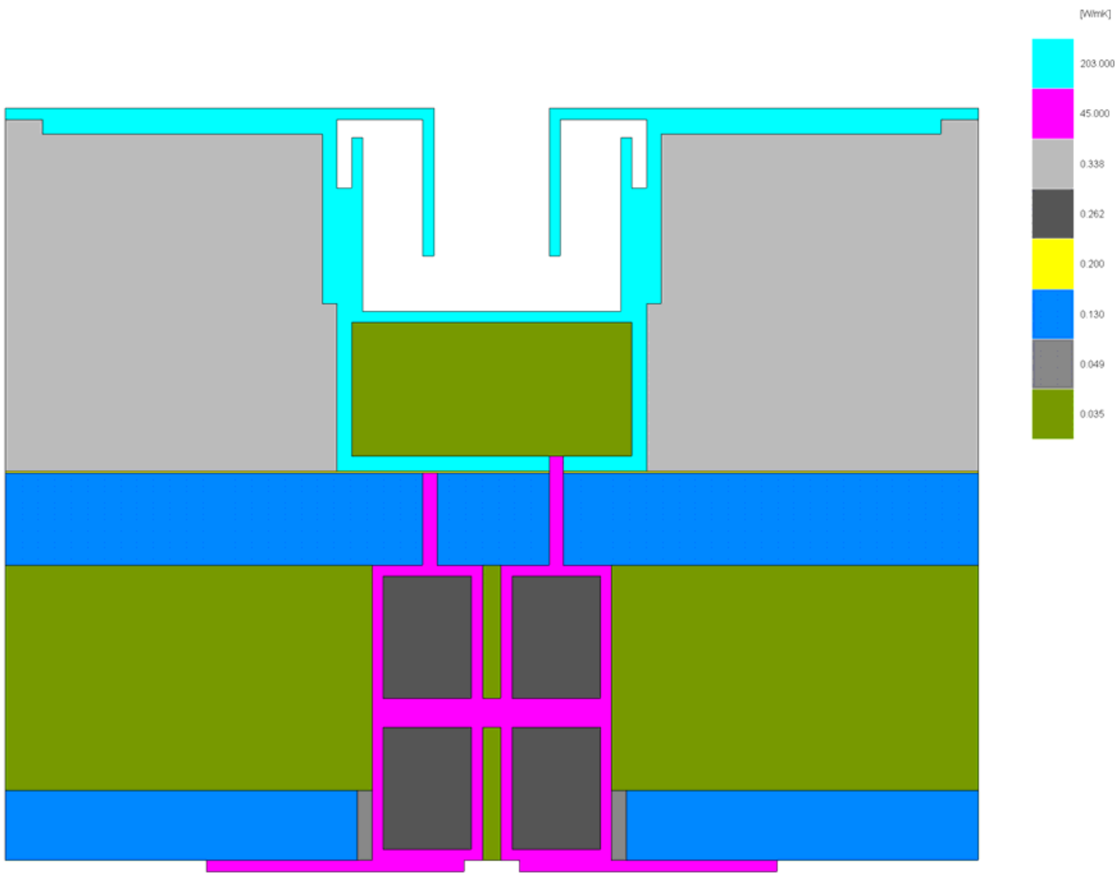
Number of nodes = 51688
Heat flow divergence for total object = 0.000265817
Heat flow divergence for worst node = 0.0943916

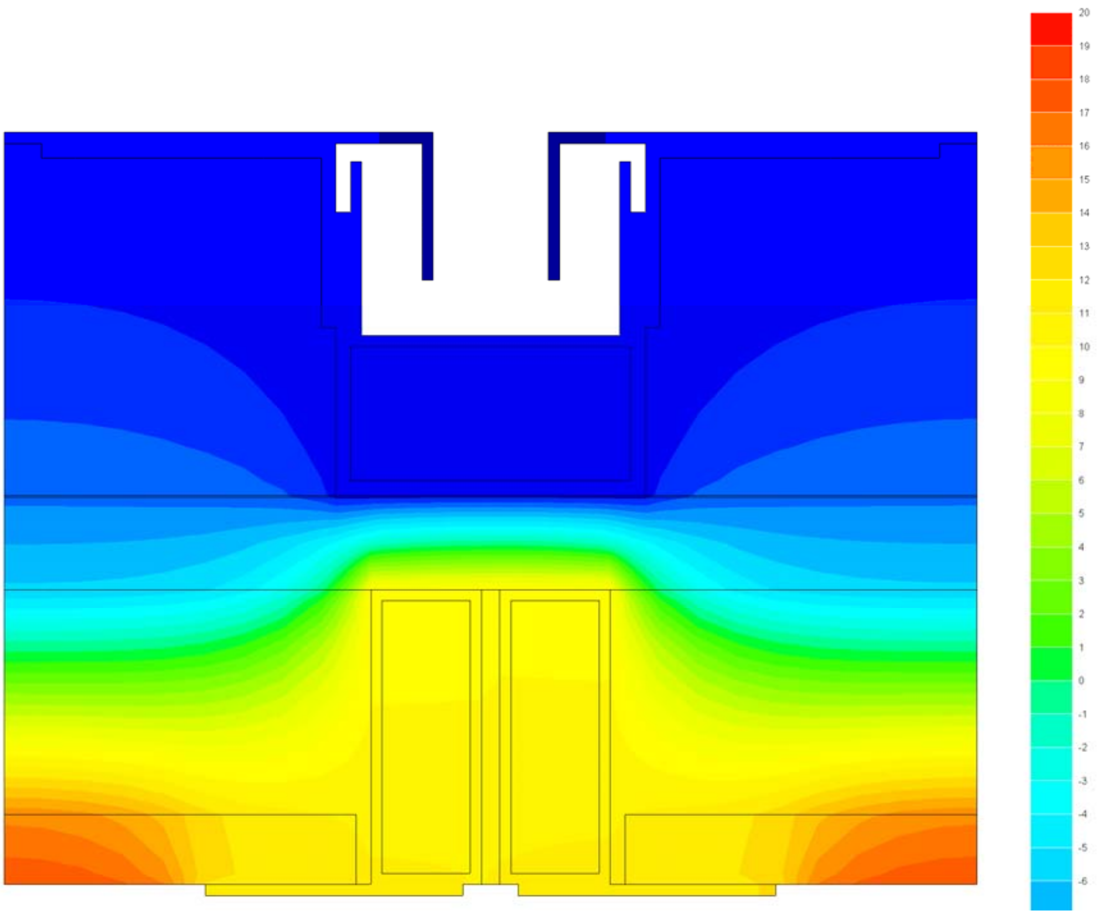
Col.	Type	Name	tmin [°C]	X	Y	Z	tmax [°C]	X	Y	Z
2	BC_SIMPL	EXTERIOR	-11.13	15	21	15	-10.77	29	19	1
3	BC_SIMPL	INTERIOR	10.94	21	2	50	17.96	0	2	36
5	MATERIAL	aluminium 99%	-11.13	15	21	15	-10.12	25	13	25
6	MATERIAL	acier	-10.24	26	14	2	12.46	5	2	15
7	MATERIAL	EPDM	-10.61	9	13	37	-2.39	16	12	25
10	MATERIAL	Panneaux OSB (O	-10.35	31	12	37	17.96	0	2	36
11	MATERIAL	Polystyrène ext	-5.83	41	10	1	15.77	0	4	36
16	EQUIMAT		-10.88	20	18	36	-10.20	24	14	25
17	EQUIMAT		-11.03	0	25	36	-8.26	0	13	50

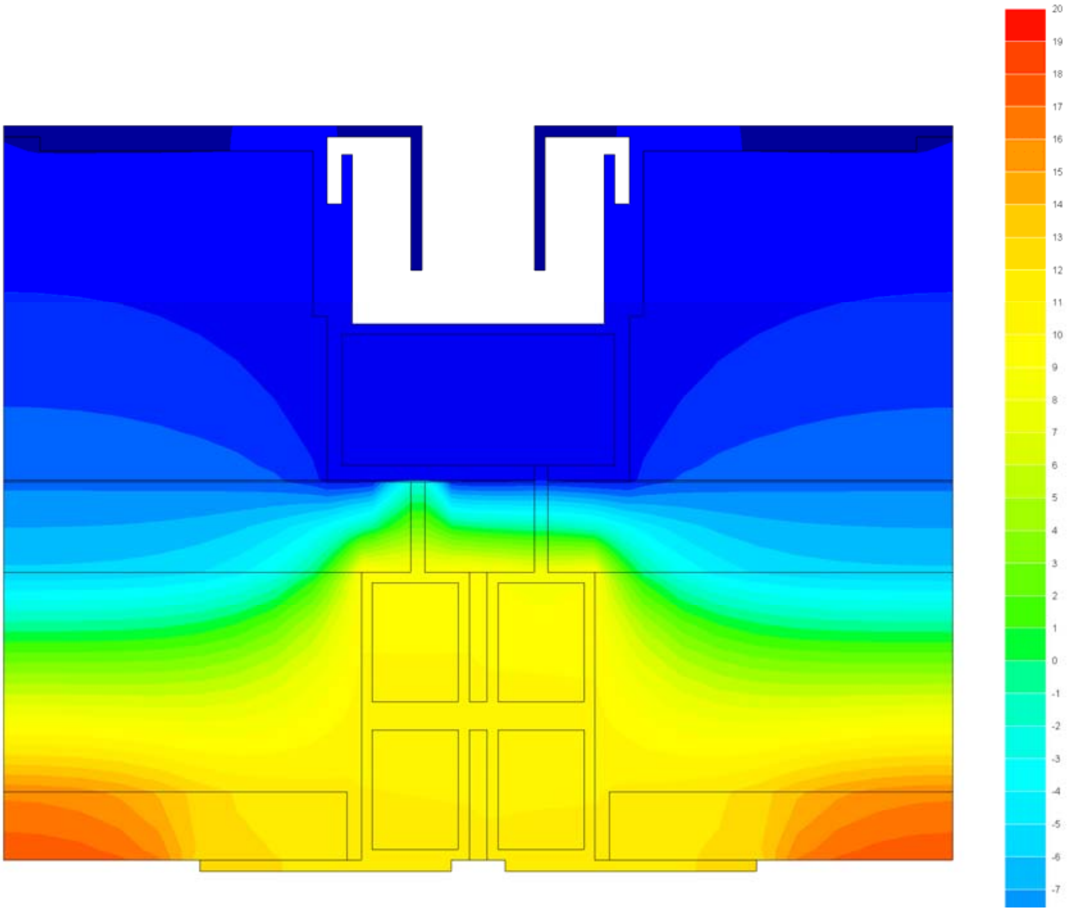
Col.	Type	Name	ta [°C]	Flow in [W]	Flow out [W]
2	BC_SIMPL	EXTERIOR		0.00	16.72
3	BC_SIMPL	INTERIOR		16.72	0.00

Again, the results don't change…

2. Filling the aluminum frame







TRISCO - Calculation Results

TRISCO data file: with insulation in the aluminum frame.trc

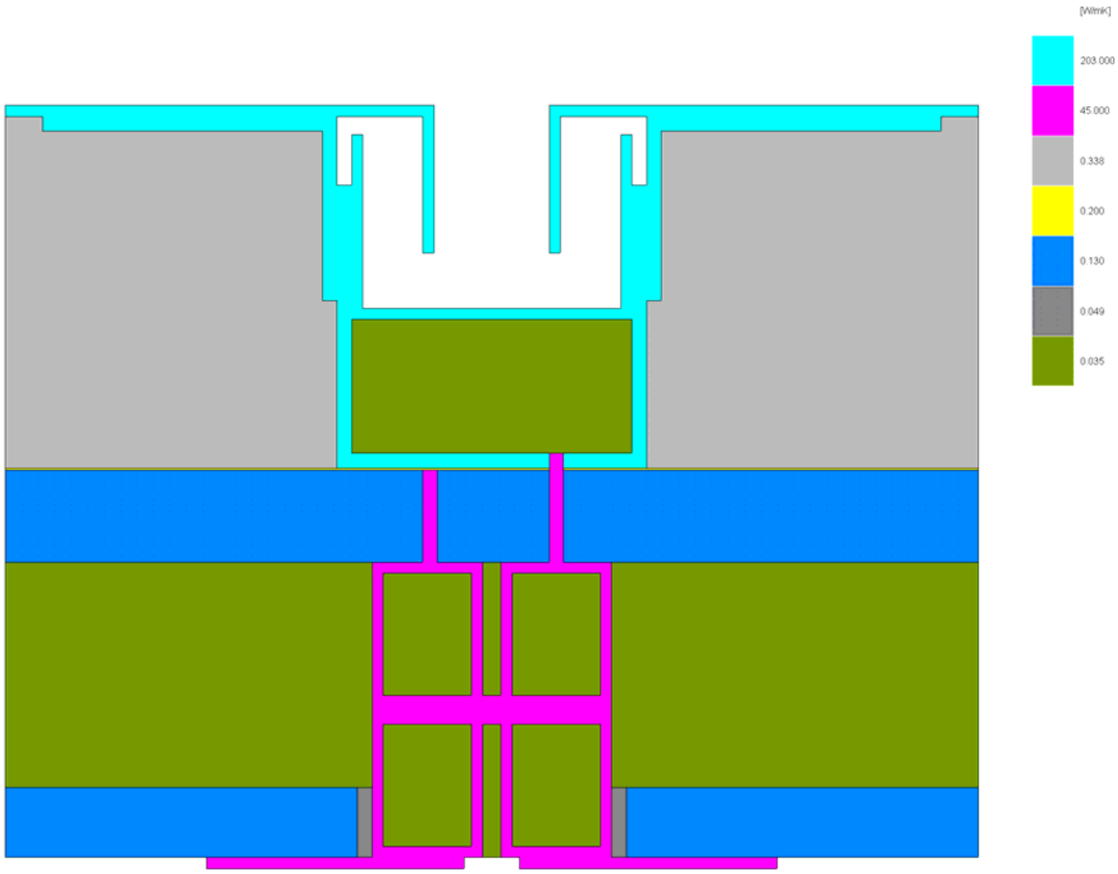
Number of nodes = 51688
Heat flow divergence for total object = 0.00012813
Heat flow divergence for worst node = 0.0579329

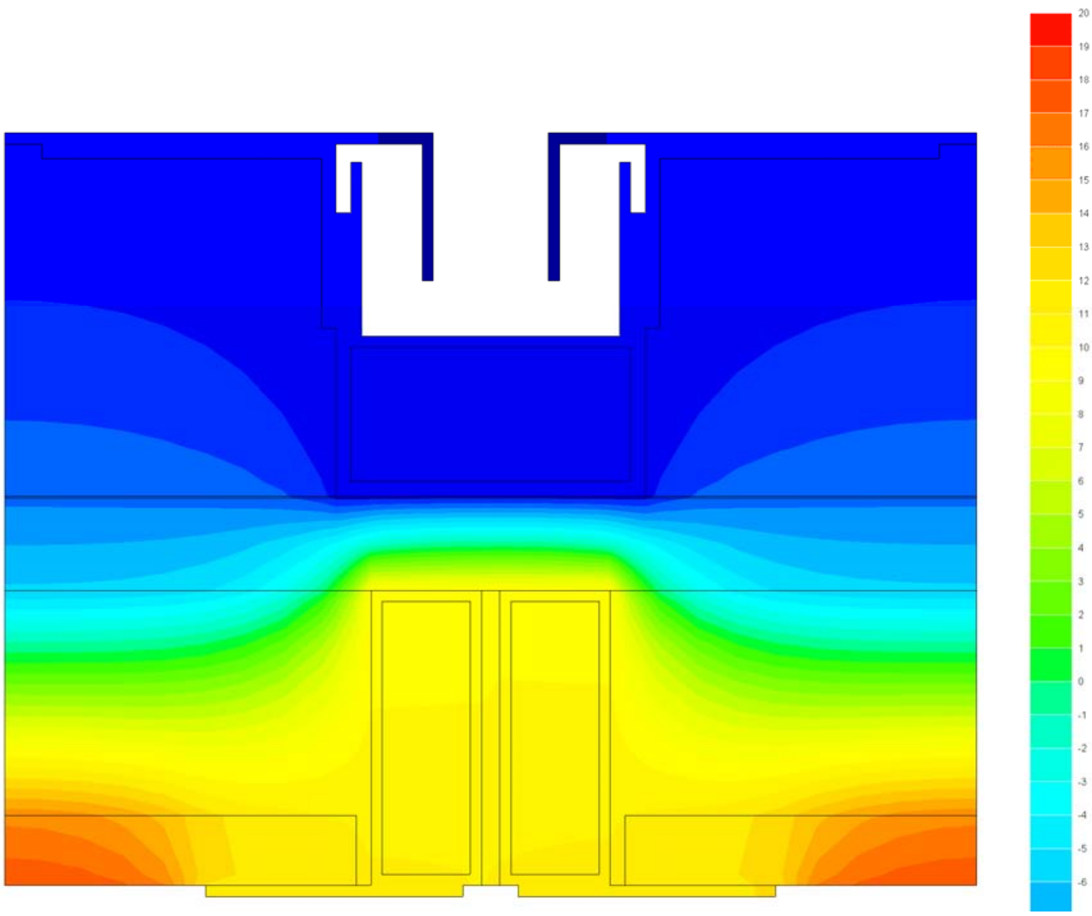
Col.	Type	Name	tmin [°C]	X	Y	Z	tmax [°C]	X	Y	Z
2	BC_SIMPL	EXTERIOR	-11.12	16	21	36	-10.77	29	19	1
3	BC_SIMPL	INTERIOR	10.94	21	2	50	17.96	0	2	15
5	MATERIAL	aluminium 99%	-11.12	16	21	36	-10.11	25	13	25
6	MATERIAL	acier	-10.24	26	14	2	12.45	5	2	15
7	MATERIAL	EPDM	-10.60	9	13	37	-2.37	16	12	25
10	MATERIAL	Panneaux OSB (O	-10.34	31	12	37	17.96	0	2	15
11	MATERIAL	Polystyrène ext	-10.88	20	18	36	15.77	0	4	15
17	EQUIMAT		-11.03	0	25	36	-8.25	0	13	50
24	EQUIMAT		8.42	25	9	48	11.70	14	3	15

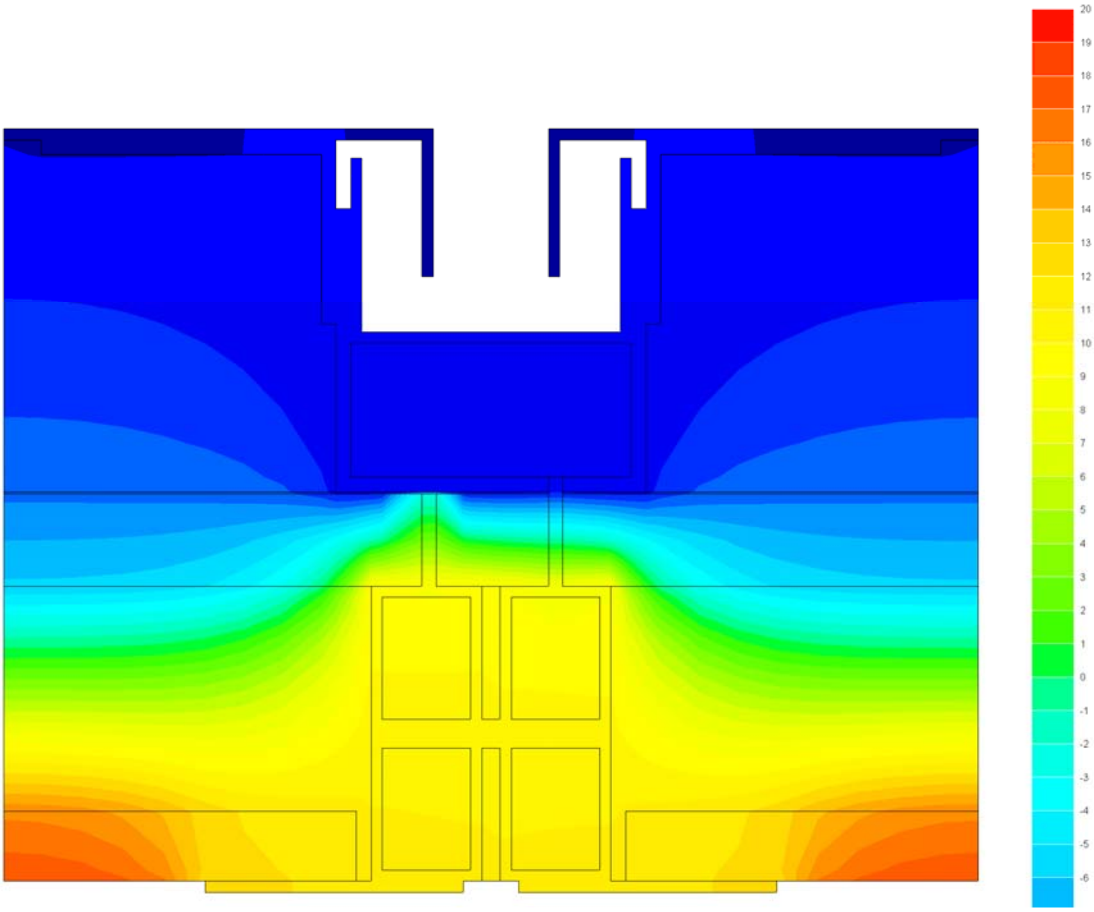
Col.	Type	Name	ta [°C]	Flow in [W]	Flow out [W]
2	BC_SIMPL	EXTERIOR		0.00	16.73
3	BC_SIMPL	INTERIOR		16.73	0.00

No changes.

3. Filling the aluminum and steel frames







TRISCO - Calculation Results

TRISCO data file: with insulation in the alu and steel frames.trc

Number of nodes = 51688
Heat flow divergence for total object = 0.000269532
Heat flow divergence for worst node = 0.094248

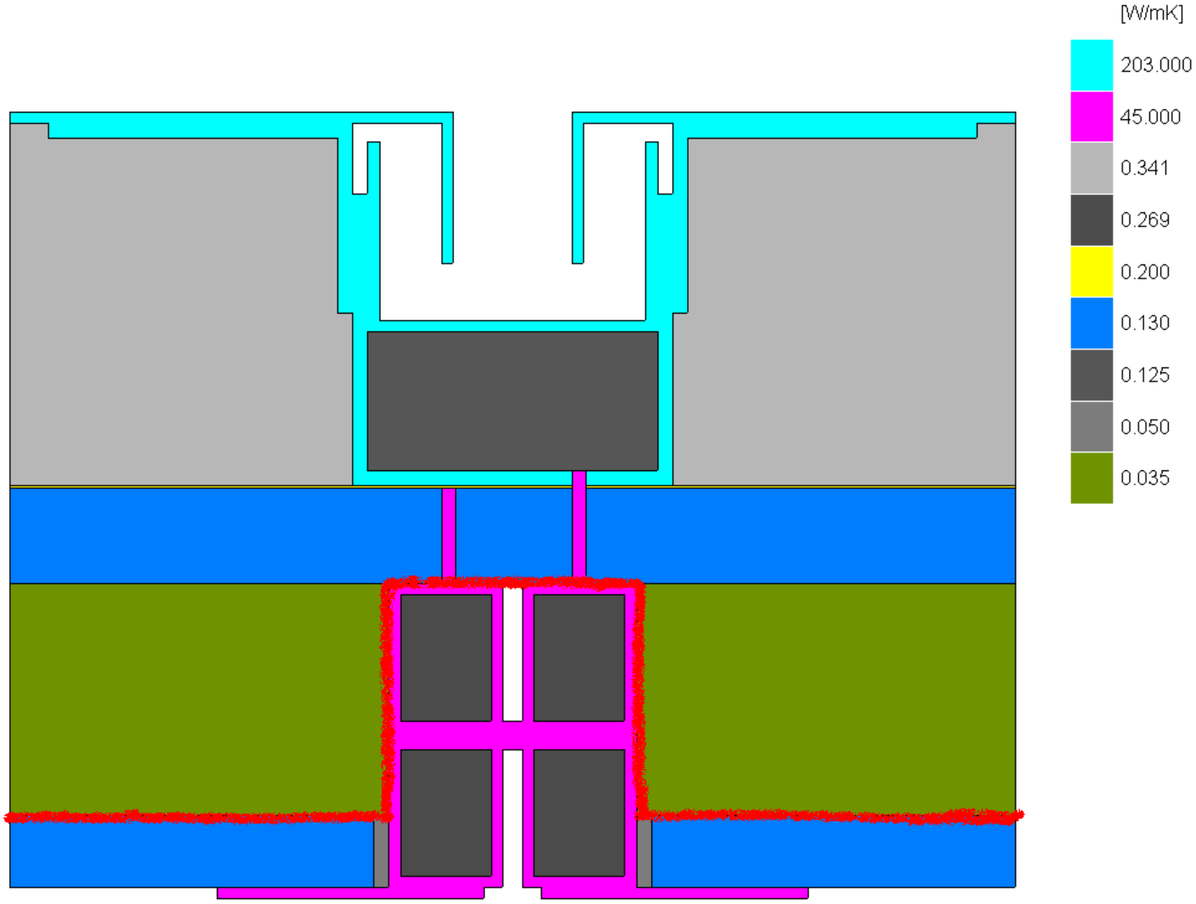
Col.	Type	Name	tmin [°C]	X	Y	Z	tmax [°C]	X	Y	Z
2	BC_SIMPL	EXTERIOR	-11.13	16	21	36	-10.77	29	19	1
3	BC_SIMPL	INTERIOR	10.95	21	2	50	17.96	0	2	36
5	MATERIAL	aluminium 99%	-11.13	16	21	36	-10.12	25	13	25
6	MATERIAL	acier	-10.24	26	14	2	12.46	5	2	15
7	MATERIAL	EPDM	-10.60	9	13	37	-2.39	16	12	25
10	MATERIAL	Panneaux OSB (O	-10.35	31	12	37	17.96	0	2	36
11	MATERIAL	Polystyrène ext	-10.88	20	18	36	15.77	0	4	36
17	EQUIMAT		-11.03	0	25	36	-8.26	0	13	50

Col.	Type	Name	ta [°C]	Flow in [W]	Flow out [W]
2	BC_SIMPL	EXTERIOR		0.00	16.72
3	BC_SIMPL	INTERIOR		16.72	0.00

No changes.

5. NODE – Smoke exhaust structure: conclusions

We can conclude from these results that adding a material, whatever it is, doesn't help solving the problems caused by an eventual condensation.
The first solution, with no material filling the 5 mm thick gap between the steel frames (which is therefore filled with ambient 20°C air) is still the best if we can prevent, as a precaution, the water vapour from entering the area, touching the cold surfaces and condensing. A vapour barrier should so be placed on the lower wooden panel, and around the steel frames, so that the temperature conditions for condensation don't cause condensation of vapour that is nearly not present in this area.



Let's temperate these solutions with the following considerations:

- As said before, 12.5°C is quite a good temperature. Knowing that if special events are allowed in the atrium, the relative humidity could go above 60% and the temperature above 20°C, and condensation could appear, but in very small quantities, not dangerous for all the concerned materials.
- No humidity problems should be expected in the wooden panels, thanks to the vapour barrier, the aluminum frame and the EPDM membrane. But even if condensation appears somewhere (which should not be huge), their capacity of absorption should make it acceptable.
- Nevertheless, possible condensation in the frame could be evacuated (as it is quite the normal case in metallic frames).

Other considerations

- Metal cladding is fixed on wooden panels: water tightness must be guaranteed for every bolt that is fixed through the EPDM membrane. For instance, a second EPDM joint can be added between the bolt head and the membrane, and the pressure exerted by the bolt on the panel should be enough to prevent water from going into the wood.

- This problem in the picture hereafter should be solved by the vapour barrier. In addition, the insulation should be extended like the purple area.