ISO 10077-2 validation of HEAT2 v7+v8, revised June 16, 2014

Thermal conductance $\boldsymbol{L}^{2D}$, thermal transmittance $\boldsymbol{U}^{f}$ and **linear** thermal transmittance $\boldsymbol{\Psi}$:

	ISO 10077	**HEAT2**	**Nodes**	**CPU**		**ISO 10077**	**HEAT2**	
Case	L^{2D} W/(m·K)	L^{2D} W/(m·K)			Diff	U^{f} W/(m^2·K)	U^{f} W/(m^2·K)	Diff
D1	0,550±0,007	0,5499 0,5511	47 000 524000	17s 30min	0%	3,22±0,06	3,218	0%
D2	0,263±0,001	0,2643 0,2644	62000 1E6	6s 30min	0,5%	1,44±0,03	1,457	1,2%
D3	0,424±0,006	0,4264	37000	3s	0,6%	2,07±0,06	2,096	1,2%
D4	0,346±0,001	0,3456	76000	3s	0%	1,36±0,01	1,361	0%
D5	0,408±0,007	0,4042	85000	10s	0,9%	2,08±0,08	2,047	-1,6%
D6	0,659±0,008 (***)	0,6588 0,6599 0,6563	61000 460000 98000	37s 22min	0% 0.1% 0.5%	4,67±0,09	4,673 4,647	0% 0.5%
D7	0,285±0,002 (***)	0,2830 0,2827	85000	4s	0,7% 0,8%	1,31±0,03	1,270 1.263	-3,0% -3,6%
D8	0,181±0,003	0,1805	83000	6s	0%	1,03±0,02*	1,020	0%
D9	0,207±0,001	0,2067	59000	2s	0%	3,64±0,01**	3,627	0%

	ISO 10077	**HEAT2**	**Nodes**	**CPU**		**ISO 10077**	**HEAT2**	
Case	L^{2D} W/(m·K)	L^{2D} W/(m·K)			Diff	Ψ W/(m·K)	Ψ W/(m·K)	Diff
D10	0,481±0,004	0,4854 0,4858	76 000 624000	4s 160s	0,9 %	0,084±0,004	0,0877	4,4 %

EN ISO 10077-2 states that the difference of $\boldsymbol{L}^{2D}$ should not be more than 3%. HEAT2 gives a maximum difference of 0,9% and complies to the standard.

The HEAT2 calculations actually use more nodes than needed (according to EN ISO 10211:2007) in order to get higher accuracy. In fact, about 2000 nodes are sufficient for case D1 to comply with the EN ISO 10211-2 requirement for mesh sub-division (this will give $\boldsymbol{L}^{2D}$ = 0.540, i.e. about 2% difference from 0.5511). Note that HEAT2 calculates each case within a few seconds even with a large amount of nodes.

- "CPU" is the calculation time on a Intel Core 2 Duo 2,4 GHz.
- Values in blue are calculated using a special version of HEAT2 with 4 million nodes.
- (*) This value should probably be 1,02±0,02 (because 0,181/0,177=1,023).
- (**) This value should probably be 3,63±0,02 (because 0,207/0,057=3,632).

(***) **Notes on sloping external boundaries:**

We have a comment on how to treat sloping boundaries; see e.g. case D6 and D7.

There is a need to adjust the thermal resistance of a numerical cell lying at a boundary when a sloping boundary is approximated by steps in order to simulate a boundary condition with a temperature and a surface resistance, or a given heat flux, correctly. HEAT2 v8 is capable of handling this automatically, see chapter 4.4 in [*http://www.buildingphysics.com/manuals/HEAT2_8_update.pdf*](http://www.buildingphysics.com/manuals/HEAT2_8_update.pdf)

Without this correction, the boundary resistances will be somewhat too low (leading to a somewhat too high total heat flow. The surface temperatures will be too low on the cold side, and too high on the warm side.

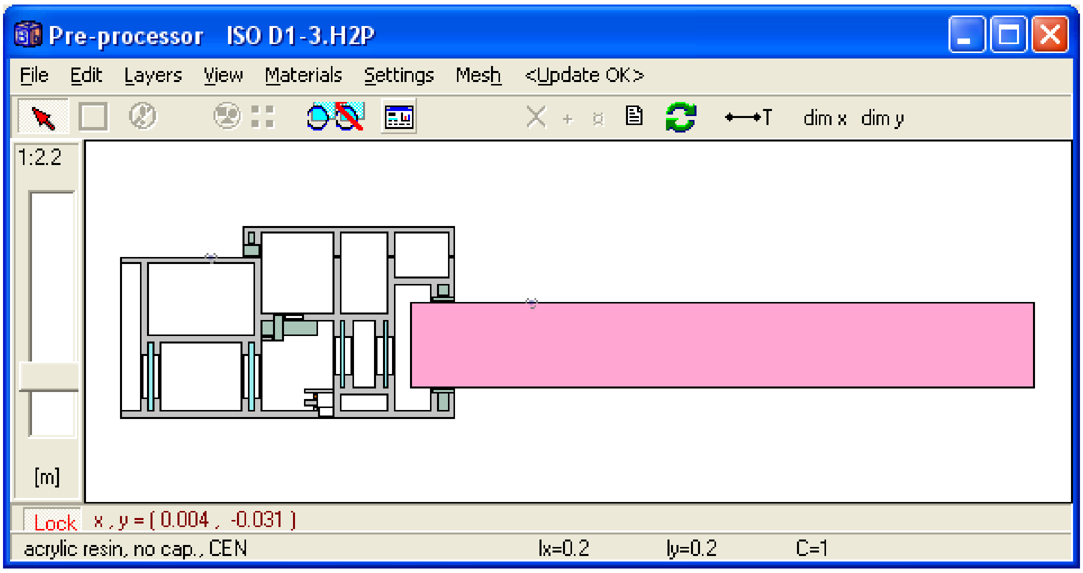
The difference for the total heat flow is only a few per-mille for the cases D6 and D7, so the correction here is a bit academic. There could however be cases where the correction can lead to many per cents difference of the total heat flow (and of course surface temperatures).

We *have sent a note about this to the ISO committee.*

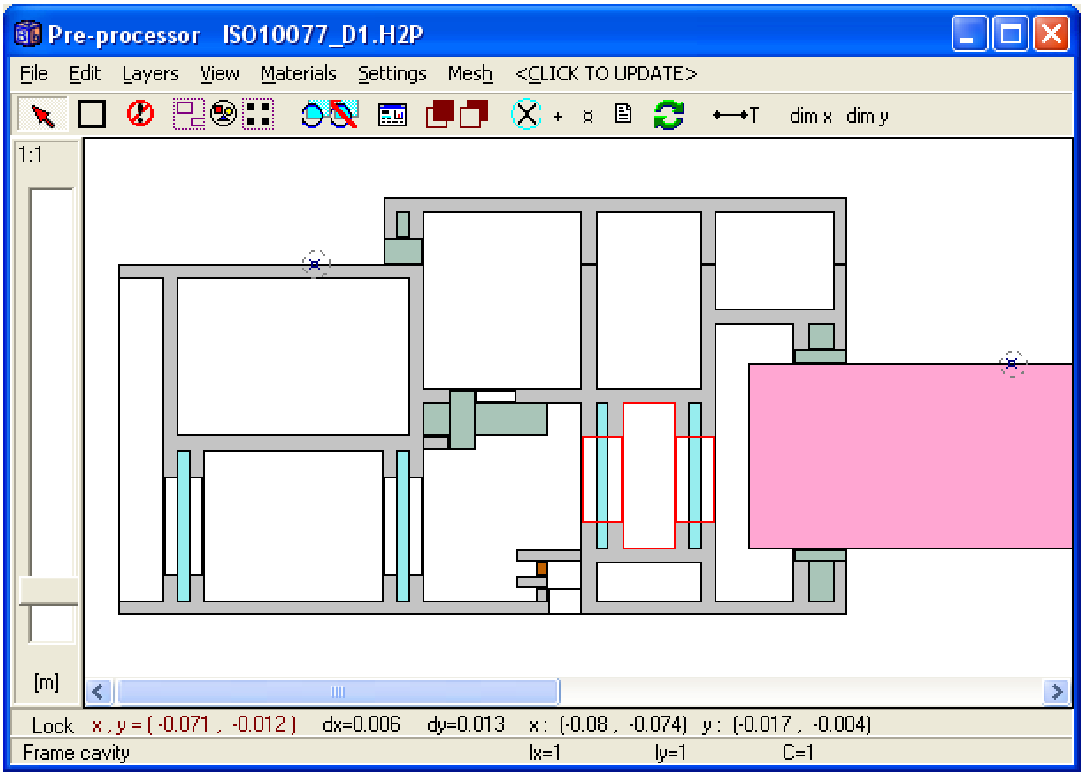
See comments for cases D6 and D7 below.

Case D1

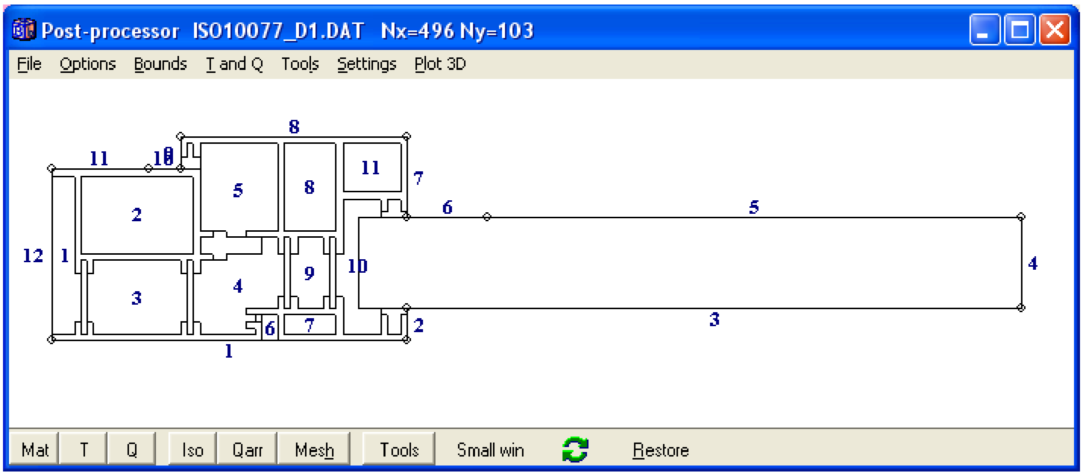
Input given in pre-processor:



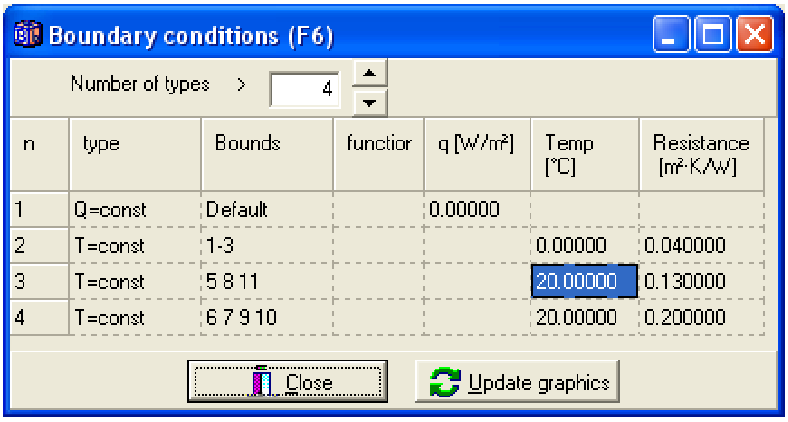
Frame cavities are drawn using the item “Frame cavity” in the material list. Note that coherent “Frame cavity” rectangles will produce a final cavity, see e.g. the three rectangles marked in red below (rectangle marked “4, 9, 10” in figure further down). Also note that two points to open boundary segments is placed here (to be able to give different boundary conditions with R=0.13 and R=0.20):



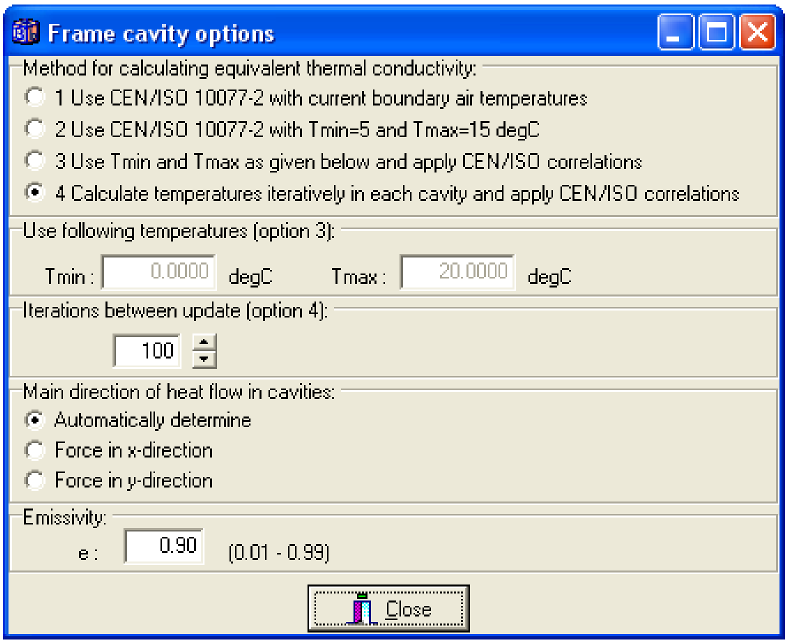
Generated frame cavity numbers (1-11) and boundary segments (1-12):



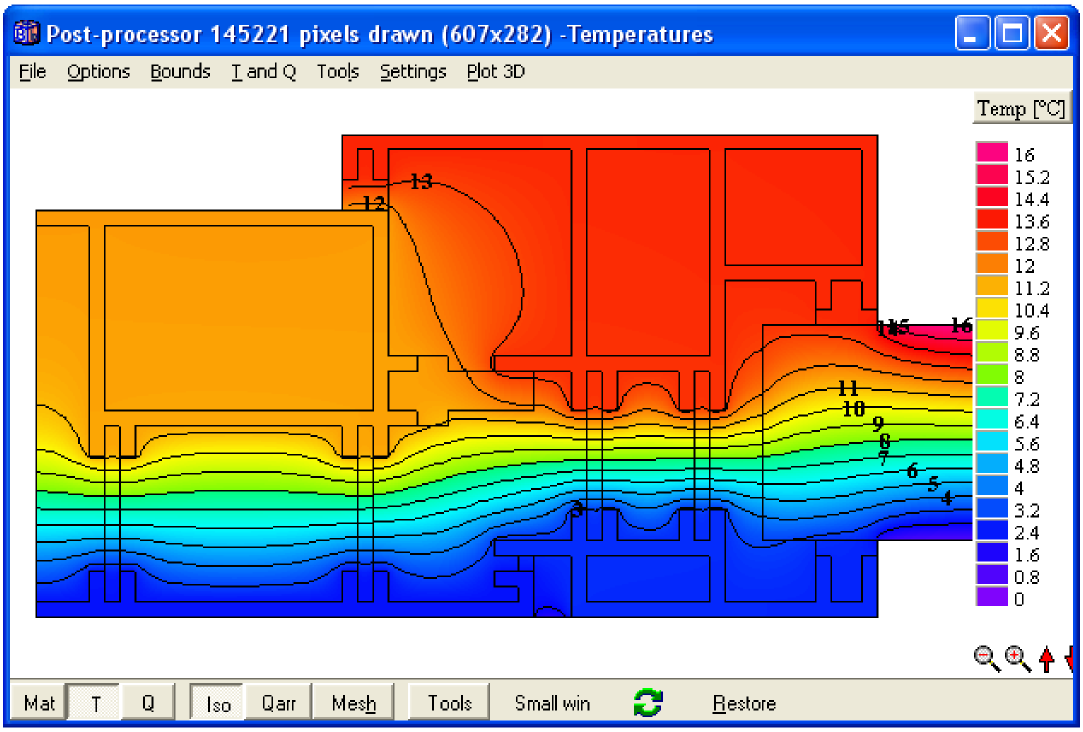
Boundary conditions (1-4) specified for boundary segments numbers (1-12):



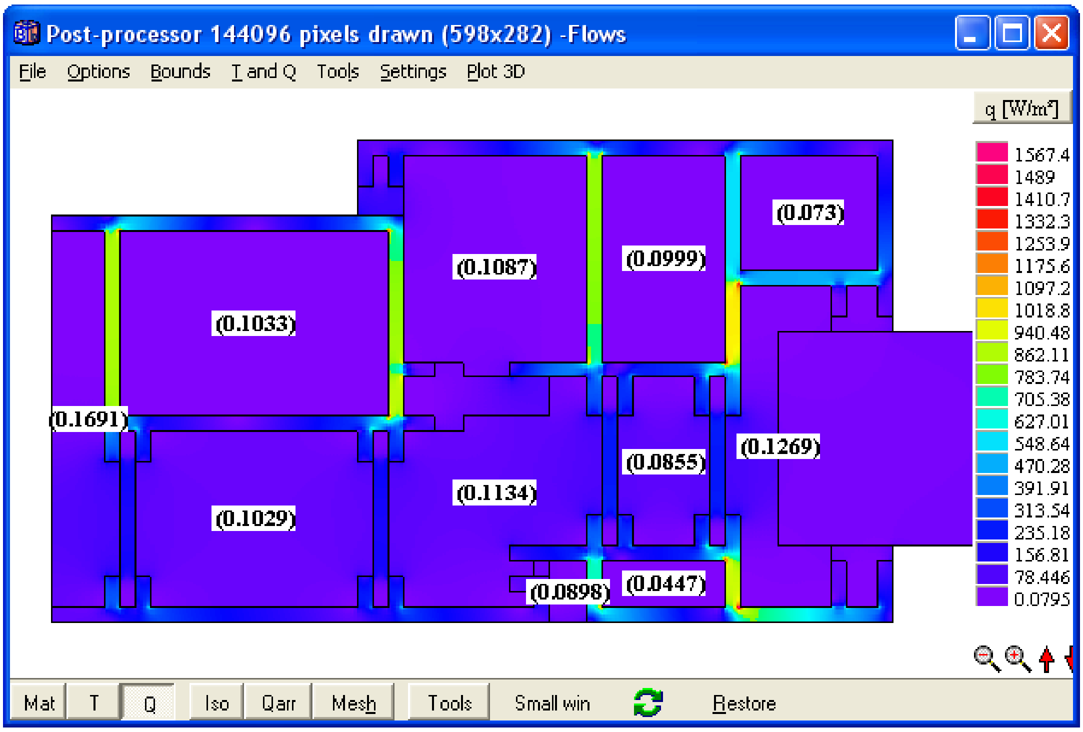
Frame cavity options dialogue:



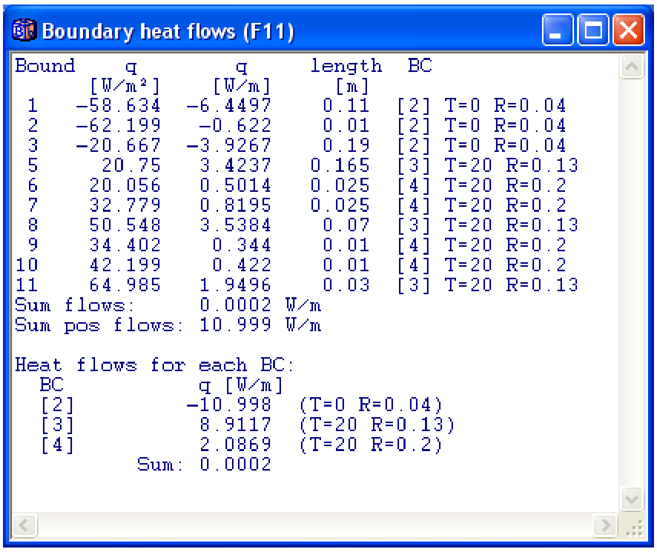
Calculated temperatures and isotherms:



Calculated heat flow intensities and equivalent thermal conductivities for the cavities:



Calculated heat flows:


Boundary heat flows (F11)

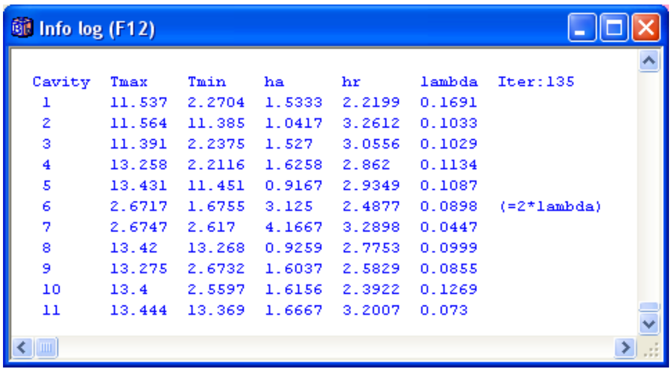
Bound	q [W/m²]	q [W/m]	length [m]	BC
1	-58.634	-6.4497	0.11	[2] T=0 R=0.04
2	-62.199	-0.622	0.01	[2] T=0 R=0.04
3	-20.667	-3.9267	0.19	[2] T=0 R=0.04
5	20.75	3.4237	0.165	[3] T=20 R=0.13
6	20.056	0.5014	0.025	[4] T=20 R=0.2
7	32.779	0.8195	0.025	[4] T=20 R=0.2
8	50.548	3.5384	0.07	[3] T=20 R=0.13
9	34.402	0.344	0.01	[4] T=20 R=0.2
10	42.199	0.422	0.01	[4] T=20 R=0.2
11	64.985	1.9496	0.03	[3] T=20 R=0.13

Sum flows: 0.0002 W/m
Sum pos flows: 10.999 W/m

Heat flows for each BC:

BC	q [W/m]	
[2]	-10.998	(T=0 R=0.04)
[3]	8.9117	(T=20 R=0.13)
[4]	2.0869	(T=20 R=0.2)
Sum:	0.0002	

The info log (F12) gives calculated equivalent thermal conductivity for the cavities:


Info log (F12)

Cavity	Tmax	Tmin	ha	hr	lambda	Iter:135
1	11.537	2.2704	1.5333	2.2199	0.1691	
2	11.564	11.385	1.0417	3.2612	0.1033	
3	11.391	2.2375	1.527	3.0556	0.1029	
4	13.258	2.2116	1.6258	2.862	0.1134	
5	13.431	11.451	0.9167	2.9349	0.1087	
6	2.6717	1.6755	3.125	2.4877	0.0898	(=2*lambda)
7	2.6747	2.617	4.1667	3.2898	0.0447	
8	13.42	13.268	0.9259	2.7753	0.0999	
9	13.275	2.6732	1.6037	2.5829	0.0855	
10	13.4	2.5597	1.6156	2.3922	0.1269	
11	13.444	13.369	1.6667	3.2007	0.073	

The thermal conductance becomes using the heat flow through the external boundary (see above)

$$L^{2D} = 10{,}998/20=0{,}5499 \text{ W/(m·K)}$$

and the thermal transmittance becomes

$$U^{f} = (L^{2D}\text{-}U_{p}\cdot b_{p})/b_{f} = (0{,}5499\text{-}1{,}03093\cdot 0{,}19)/0{,}11=3{,}218 \text{ W/(m}^{2}\cdot\text{K)}$$

where

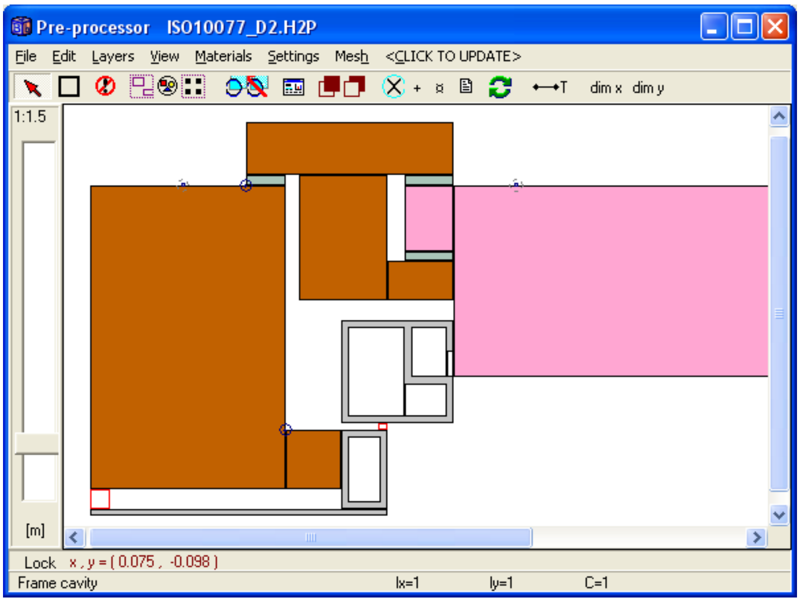
$$U_{p} =1/(0{,}13+0{,}04+0{,}028/0{,}035)=1{,}03093 \text{ W/(m}^{2}\cdot\text{K)}$$

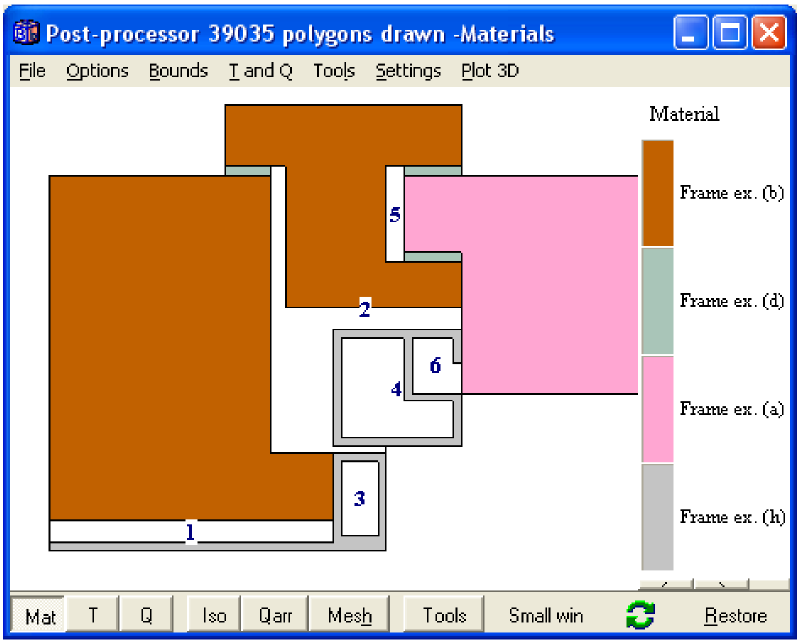
To make this calculation please do as follows:

1. Open file **ISO10077_D1.dat**
2. Start the calculation (press F9)
3. Answer yes on the question “Cavity number 6 lies at a boundary. Do you want to use twice the equivalent lambda?”. This is a slightly ventilated cavity, see standard.

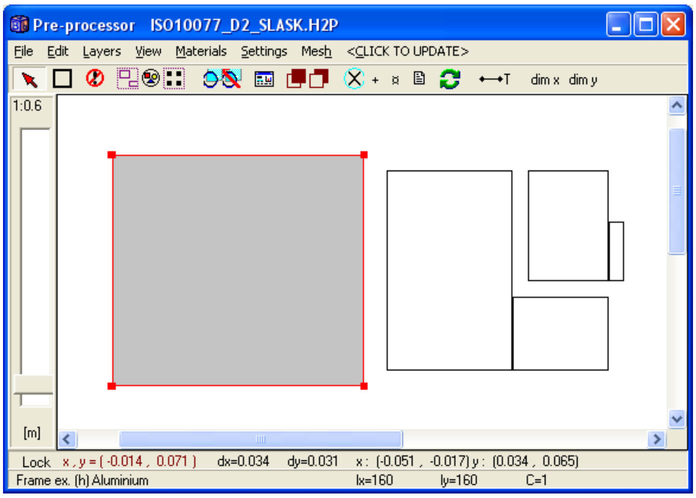
Case D2

HEAT2 will recognize all 6 cavities, see numbers below. It is enough to draw two “Frame cavity” rectangles in order to encapsulate cavity 1 and 2, respectively, see rectangles marked in red below.

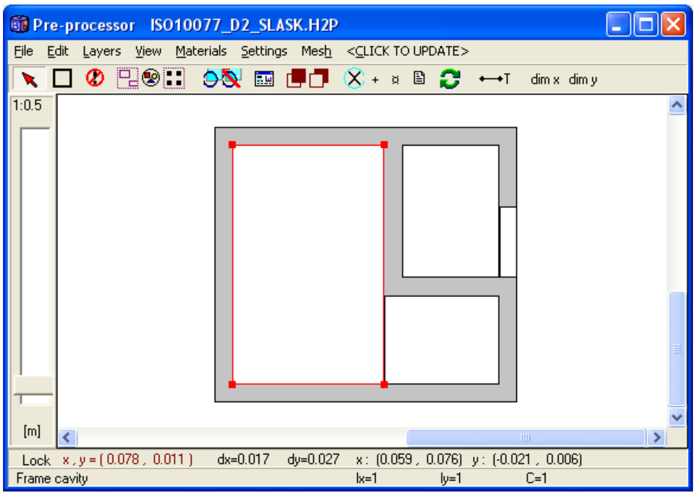




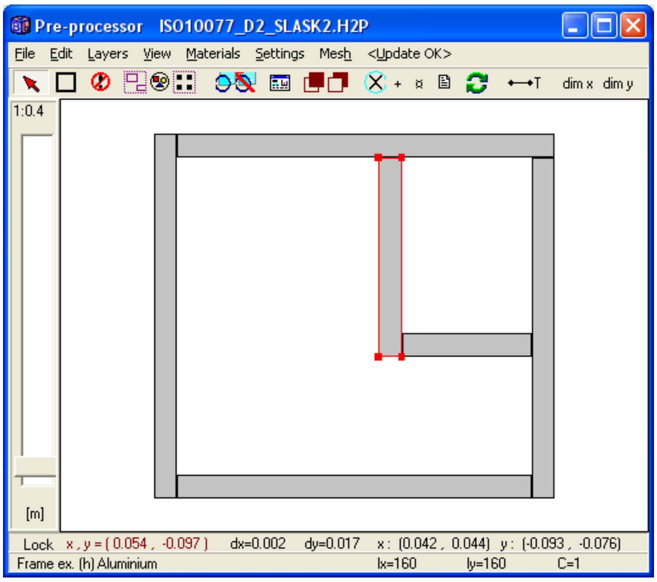
Note that for the aluminum part with cavities 4 and 6 it is enough to draw one aluminum rectangle plus 4 “Frame cavity” rectangles (in total 5 drawn rectangles):

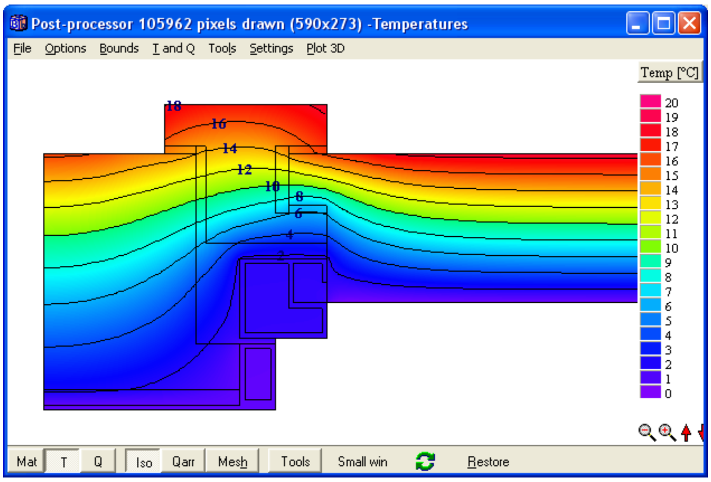


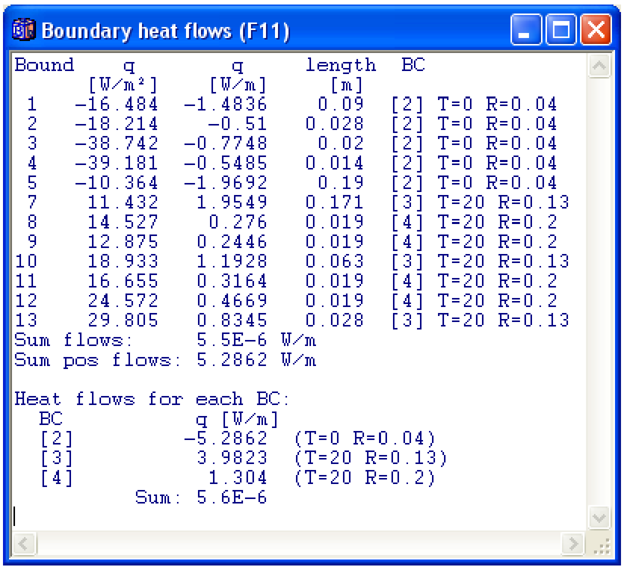
These five rectangles added gives:



Alternatively, this could have been made with six drawn aluminum rectangles:







Boundary heat flows (F11)

Bound	q [W/m²]	q [W/m]	length [m]	BC
1	-16.484	-1.4836	0.09	[2] T=0 R=0.04
2	-18.214	-0.51	0.028	[2] T=0 R=0.04
3	-38.742	-0.7748	0.02	[2] T=0 R=0.04
4	-39.181	-0.5485	0.014	[2] T=0 R=0.04
5	-10.364	-1.9692	0.19	[2] T=0 R=0.04
7	11.432	1.9549	0.171	[3] T=20 R=0.13
8	14.527	0.276	0.019	[4] T=20 R=0.2
9	12.875	0.2446	0.019	[4] T=20 R=0.2
10	18.933	1.1928	0.063	[3] T=20 R=0.13
11	16.655	0.3164	0.019	[4] T=20 R=0.2
12	24.572	0.4669	0.019	[4] T=20 R=0.2
13	29.805	0.8345	0.028	[3] T=20 R=0.13

Sum flows: 5.5E-6 W/m
Sum pos flows: 5.2862 W/m

Heat flows for each BC:

BC	q [W/m]	
[2]	-5.2862	(T=0 R=0.04)
[3]	3.9823	(T=20 R=0.13)
[4]	1.304	(T=20 R=0.2)
Sum:	5.6E-6	

The thermal conductance becomes

$$L^{2D} = 5{,}2862/20=0{,}2643 \text{ W/(m·K)}$$

and the thermal transmittance becomes

$$U^f = (L^{2D}\text{-}U_p\cdot b_p)/b_f = (0{,}2643\text{-}0{,}54730\cdot 0{,}19)/0{,}11=1{,}457 \text{ W/(m}^2\text{·K)}$$

where

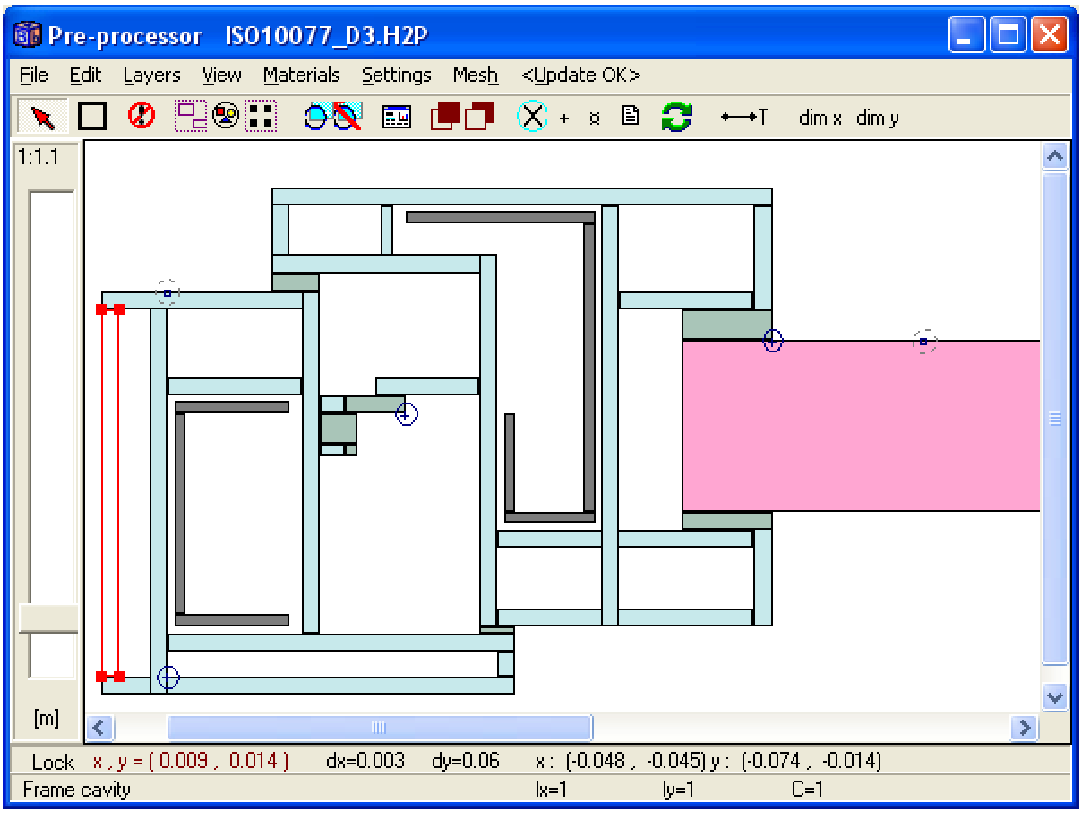
$$U_p = 1/(0{,}13+0{,}04+0{,}058/0{,}035)=0{,}54730 \text{ W/(m}^2\text{·K)}$$

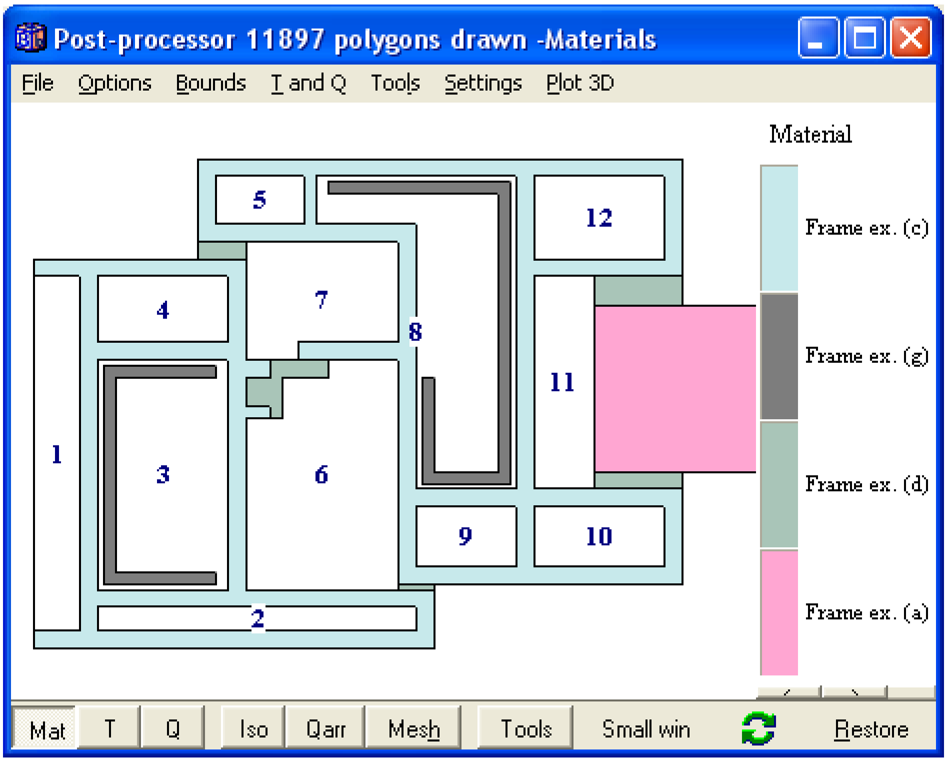
To make this calculation please do as follows:

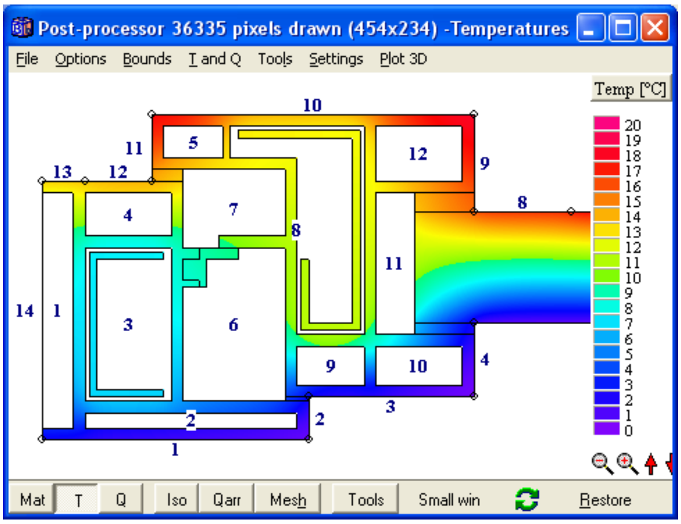
1. Open file **ISO10077_D2.dat**
2. Start the calculation (press F9)
3. Answer **no** on the question “Cavity number 2 lies at a boundary. Do you want to use twice the equivalent lambda?”

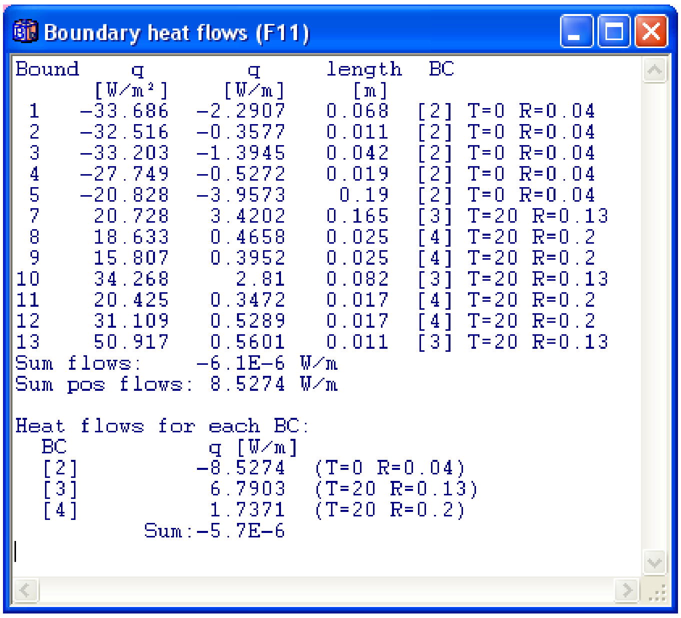
Case D3

HEAT2 will recognize all 12 cavities. It is enough to draw one "Frame cavity" in order to encapsulate cavity 1, see red rectangle below (this rectangle could also have filled the cavity area).









Bound	q [W/m²]	q [W/m]	length [m]	BC
1	-33.686	-2.2907	0.068	[2] T=0 R=0.04
2	-32.516	-0.3577	0.011	[2] T=0 R=0.04
3	-33.203	-1.3945	0.042	[2] T=0 R=0.04
4	-27.749	-0.5272	0.019	[2] T=0 R=0.04
5	-20.828	-3.9573	0.19	[2] T=0 R=0.04
7	20.728	3.4202	0.165	[3] T=20 R=0.13
8	18.633	0.4658	0.025	[4] T=20 R=0.2
9	15.807	0.3952	0.025	[4] T=20 R=0.2
10	34.268	2.81	0.082	[3] T=20 R=0.13
11	20.425	0.3472	0.017	[4] T=20 R=0.2
12	31.109	0.5289	0.017	[4] T=20 R=0.2
13	50.917	0.5601	0.011	[3] T=20 R=0.13

Sum flows: -6.1E-6 W/m
Sum pos flows: 8.5274 W/m

Heat flows for each BC:

BC	q [W/m]	
[2]	-8.5274	(T=0 R=0.04)
[3]	6.7903	(T=20 R=0.13)
[4]	1.7371	(T=20 R=0.2)
	Sum: -5.7E-6	

The thermal conductance becomes

$$L^{2D} = 8{,}5274/20 = 0{,}4264 \text{ W/(m·K)}$$

and the thermal transmittance becomes

$$U^{f} = (L^{2D} - U_p \cdot b_p)/b_f = (0{,}4264 - 1{,}03093 \cdot 0{,}19)/0{,}11 = 2{,}096 \text{ W/(m}^2\text{·K)}$$

where

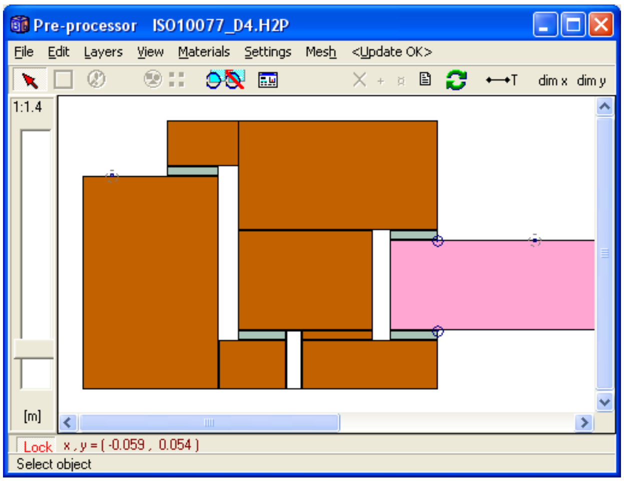
$$U_p = 1/(0{,}13 + 0{,}04 + 0{,}028/0{,}035) = 1{,}03093 \text{ W/(m}^2\text{·K)}$$

To make this calculation please do as follows:

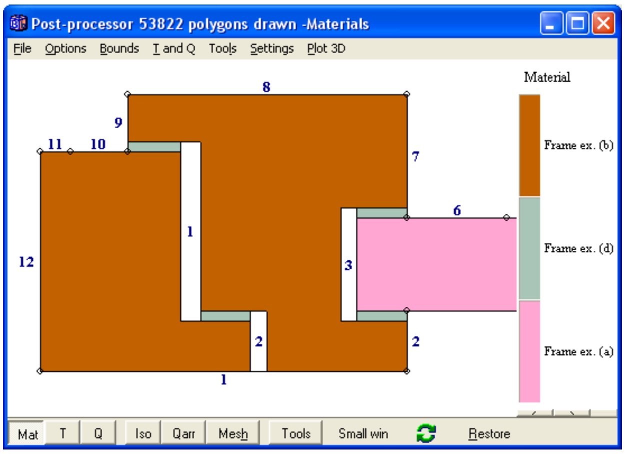
1. Open file **ISO10077_D3.dat**
2. Start the calculation (press F9)

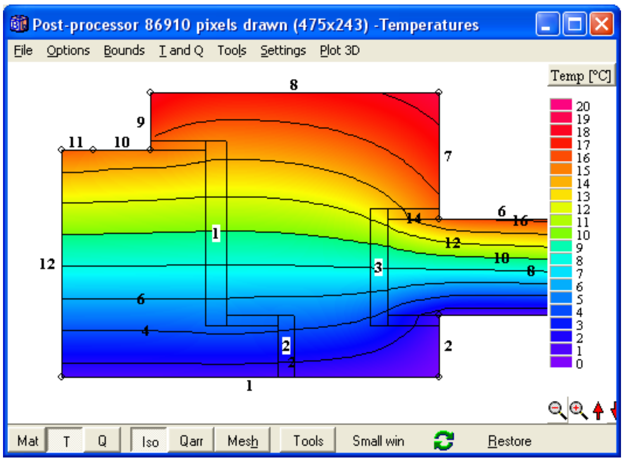
Case D4

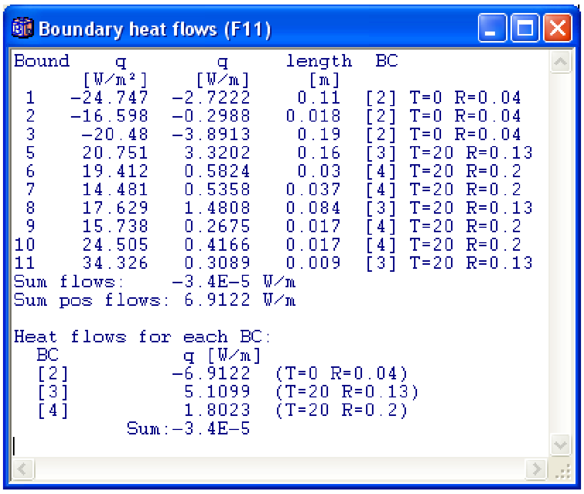
Input:



Generated cavities:







Boundary heat flows (F11)

Bound	q [W/m²]	q [W/m]	length [m]	BC
1	-24.747	-2.7222	0.11	[2] T=0 R=0.04
2	-16.598	-0.2988	0.018	[2] T=0 R=0.04
3	-20.48	-3.8913	0.19	[2] T=0 R=0.04
5	20.751	3.3202	0.16	[3] T=20 R=0.13
6	19.412	0.5824	0.03	[4] T=20 R=0.2
7	14.481	0.5358	0.037	[4] T=20 R=0.2
8	17.629	1.4808	0.084	[3] T=20 R=0.13
9	15.738	0.2675	0.017	[4] T=20 R=0.2
10	24.505	0.4166	0.017	[4] T=20 R=0.2
11	34.326	0.3089	0.009	[3] T=20 R=0.13

Sum flows: -3.4E-5 W/m
Sum pos flows: 6.9122 W/m

Heat flows for each BC:

BC	q [W/m]	
[2]	-6.9122	(T=0 R=0.04)
[3]	5.1099	(T=20 R=0.13)
[4]	1.8023	(T=20 R=0.2)
	Sum:-3.4E-5	

The thermal conductance becomes

$$L^{2D} = 6{,}9122/20=0{,}3456 \text{ W/(m·K)}$$

and the thermal transmittance becomes

$$U^{f} = (L^{2D}-U_p \cdot b_p)/b_f = (0{,}3456-1{,}03093 \cdot 0{,}19)/0{,}11=1{,}361 \text{ W/(m}^2\text{·K)}$$

where

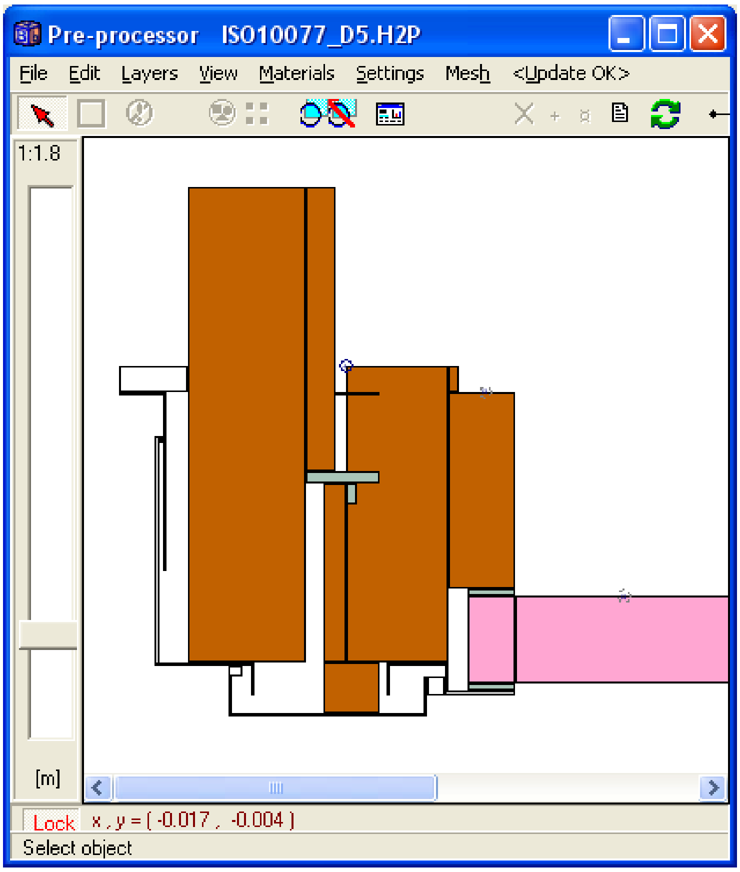
$$U_p =1/(0{,}13+0{,}04+0{,}028/0{,}035)=1{,}03093 \text{ W/(m}^2\text{·K)}$$

To make this calculation please do as follows:

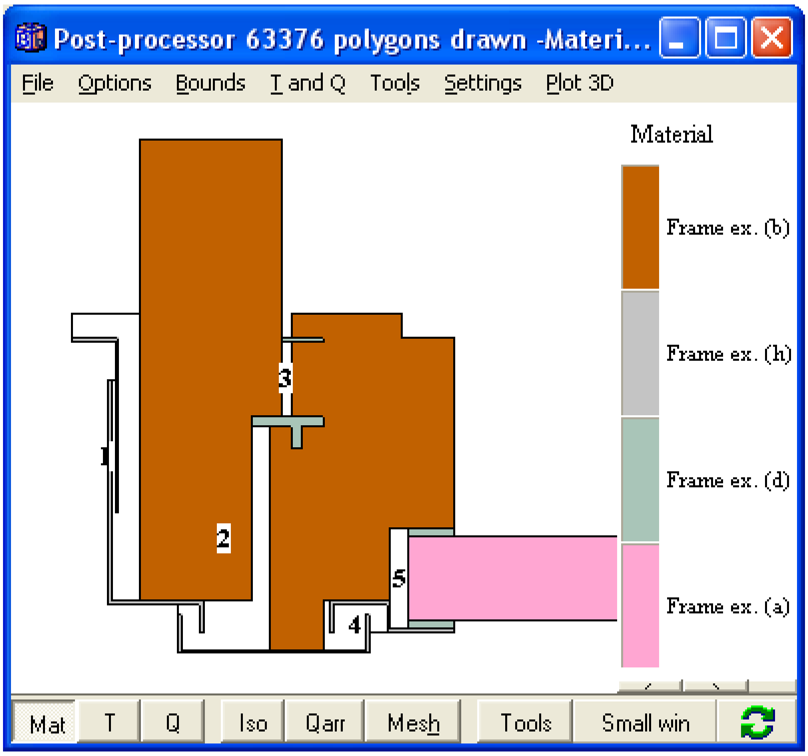
1. Open file **ISO10077_D4.dat**
2. Start the calculation (press F9)
3. Answer yes on the question "Cavity number 2 lies at a boundary. Do you want to use twice the equivalent lambda?"

Case D5

Input in pre-processor:



Generated frame cavities:

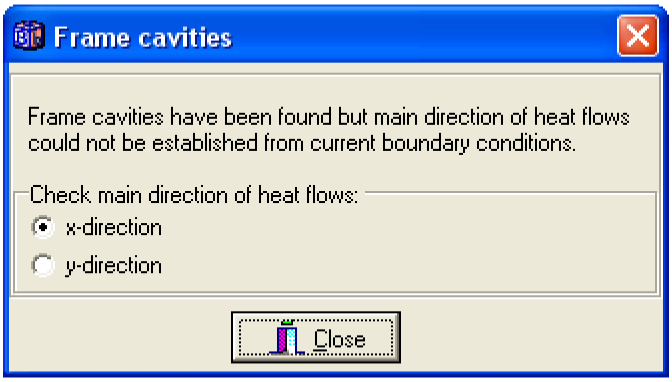


In this case we have a heat flow mainly in the x-direction for cavity 1, and a heat flow mainly in the y-direction for cavities 2, 4, 5. Since HEAT2 assumes the same direction for all cavities we need to make two different calculations. In the first one we state that the heat flow is mainly in the x-direction. This will give the equivalent thermal conductivity of cavity 1.

To make this calculation please do as follows:

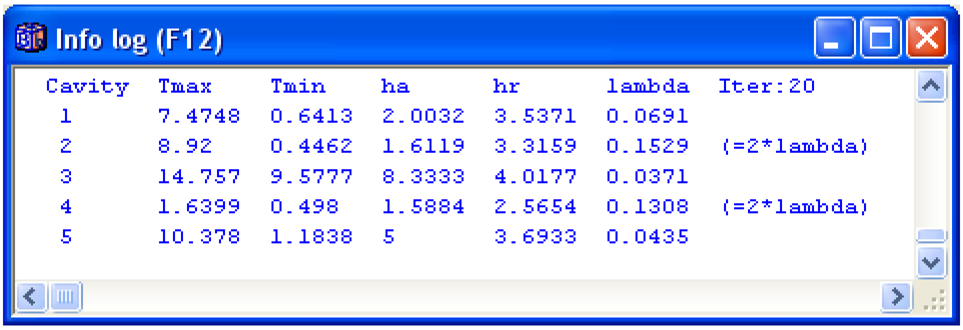
1. Open file **ISO10077_D5.dat**

2. Start the calculation (press F9)

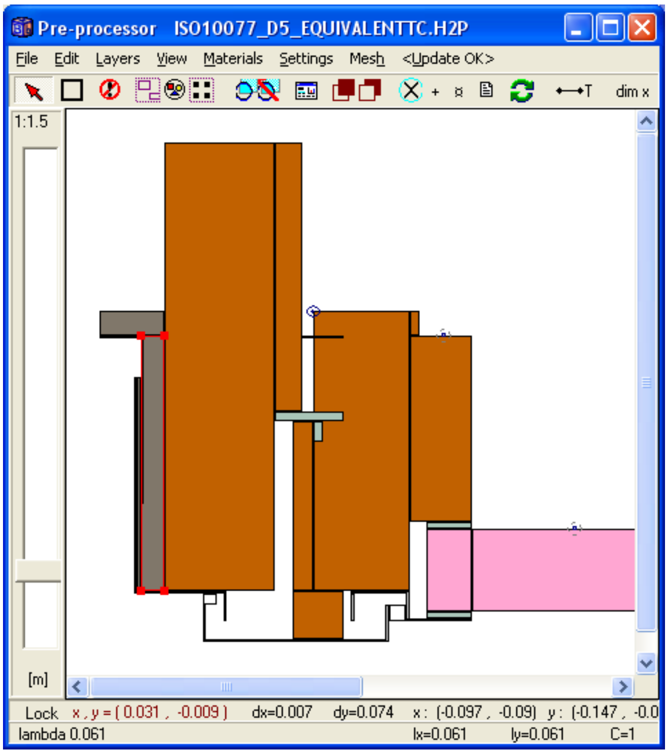
3. 

4. Answer **no** on the question “Cavity number 1 lies at a boundary. Do you want to use twice the equivalent lambda?” and yes for cavities 2 and 4.

The info log (press F12) shows that the calculated equivalent thermal conductivity of cavity 1 is 0.0691.



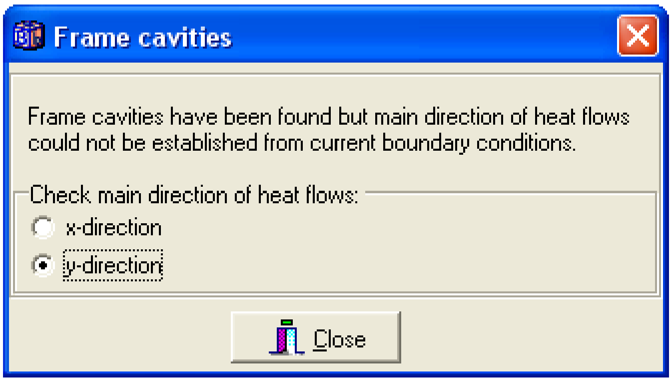
After this we make a new material in the material list with lambda=0.0691 and replaces the area for cavity 1 with the new material:



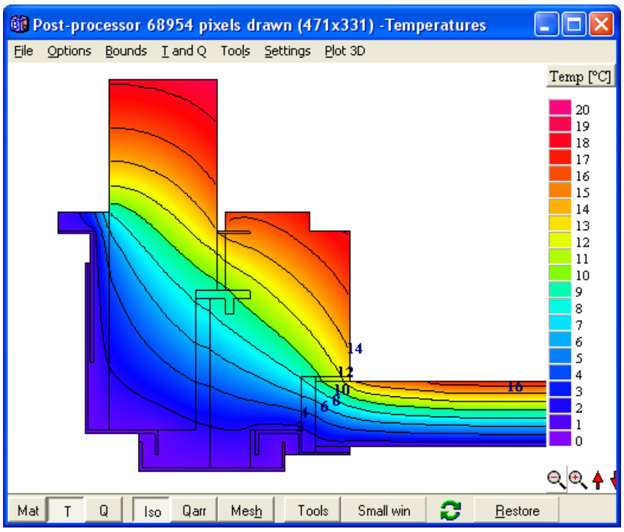
This is available here:

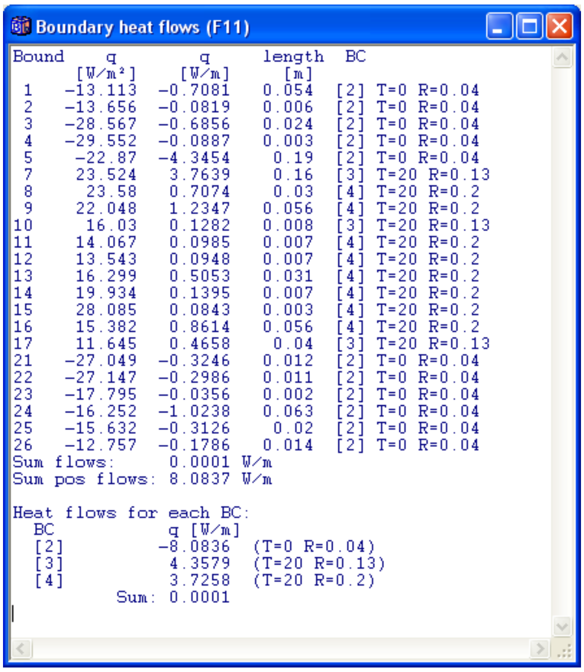
1. Open file **ISO10077_D5_equivalentTC.dat** (this will use the material file DEFAULT_ISO10077_D5.MTL. Make sure this file exists in the same folder as HEAT2.exe).

2. Start the calculation (press F9) with main direction of heat flow set to y-direction:

3. 

4. Answer yes on the question “Cavity number 1 lies at a boundary. Do you want to use twice the equivalent lambda?” and for cavity 3 (new cavity numbers are assigned).





Boundary heat flows (F11)

Bound	q [W/m²]	q [W/m]	length [m]	BC
1	-13.113	-0.7081	0.054	[2] T=0 R=0.04
2	-13.656	-0.0819	0.006	[2] T=0 R=0.04
3	-28.567	-0.6856	0.024	[2] T=0 R=0.04
4	-29.552	-0.0887	0.003	[2] T=0 R=0.04
5	-22.87	-4.3454	0.19	[2] T=0 R=0.04
7	23.524	3.7639	0.16	[3] T=20 R=0.13
8	23.58	0.7074	0.03	[4] T=20 R=0.2
9	22.048	1.2347	0.056	[4] T=20 R=0.2
10	16.03	0.1282	0.008	[3] T=20 R=0.13
11	14.067	0.0985	0.007	[4] T=20 R=0.2
12	13.543	0.0948	0.007	[4] T=20 R=0.2
13	16.299	0.5053	0.031	[4] T=20 R=0.2
14	19.934	0.1395	0.007	[4] T=20 R=0.2
15	28.085	0.0843	0.003	[4] T=20 R=0.2
16	15.382	0.8614	0.056	[4] T=20 R=0.2
17	11.645	0.4658	0.04	[3] T=20 R=0.13
21	-27.049	-0.3246	0.012	[2] T=0 R=0.04
22	-27.147	-0.2986	0.011	[2] T=0 R=0.04
23	-17.795	-0.0356	0.002	[2] T=0 R=0.04
24	-16.252	-1.0238	0.063	[2] T=0 R=0.04
25	-15.632	-0.3126	0.02	[2] T=0 R=0.04
26	-12.757	-0.1786	0.014	[2] T=0 R=0.04

Sum flows: 0.0001 W/m
Sum pos flows: 8.0837 W/m

Heat flows for each BC:

BC	q [W/m]	
[2]	-8.0836	(T=0 R=0.04)
[3]	4.3579	(T=20 R=0.13)
[4]	3.7258	(T=20 R=0.2)
Sum:	0.0001	

The thermal conductance becomes

$$L^{2D} = 8{,}0836/20 = 0{,}4042 \text{ W/(m·K)}$$

and the thermal transmittance becomes

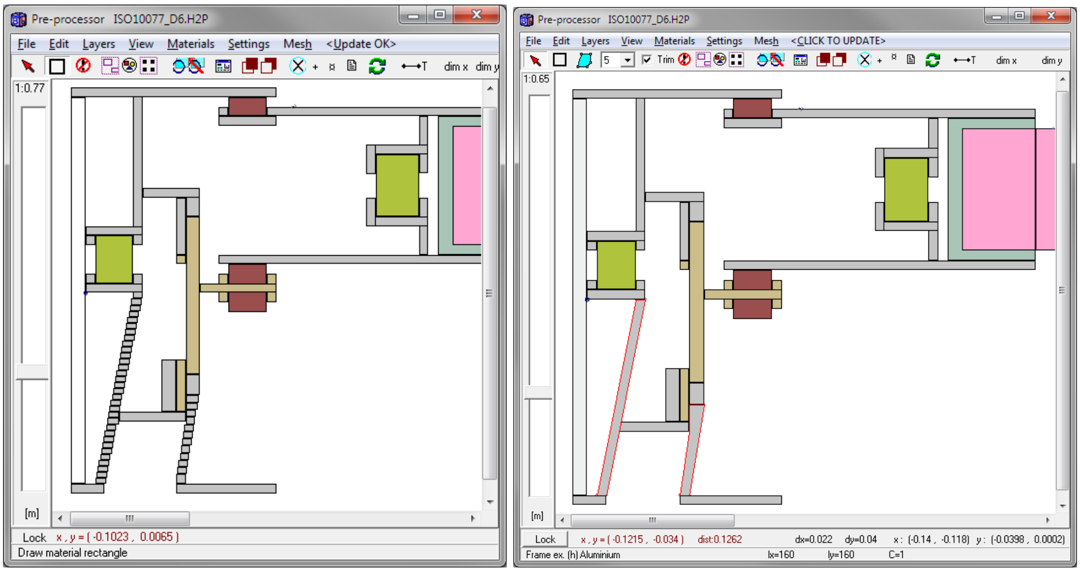
$$U^{f} = (L^{2D} - U_p \cdot b_p)/b_f = (0{,}4042 - 1{,}16861 \cdot 0{,}19)/0{,}089 = 2{,}047 \text{ W/(m}^2\text{·K)}$$

where

$$U_p = 1/(0{,}13 + 0{,}04 + 0{,}024/0{,}035) = 1{,}16861 \text{ W/(m}^2\text{·K)}$$

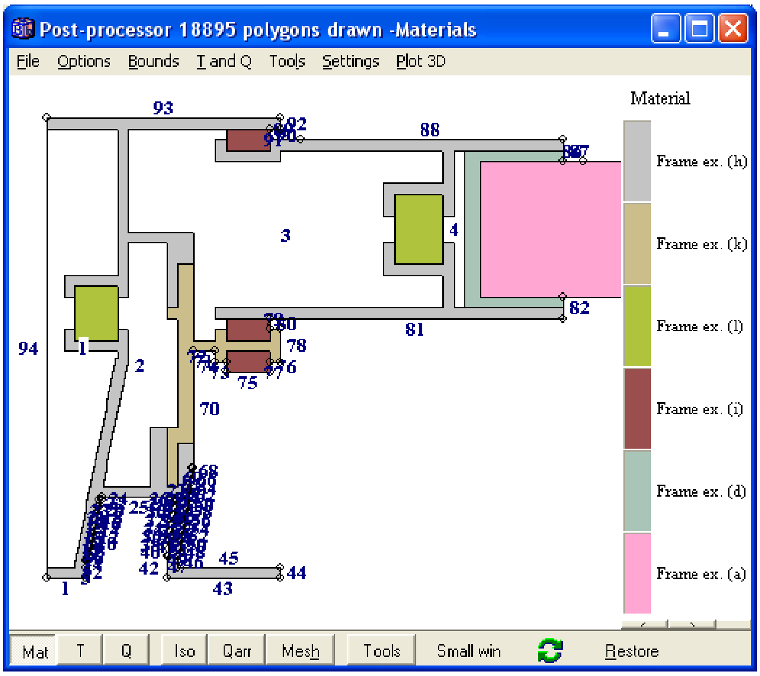
Case D6

Input:



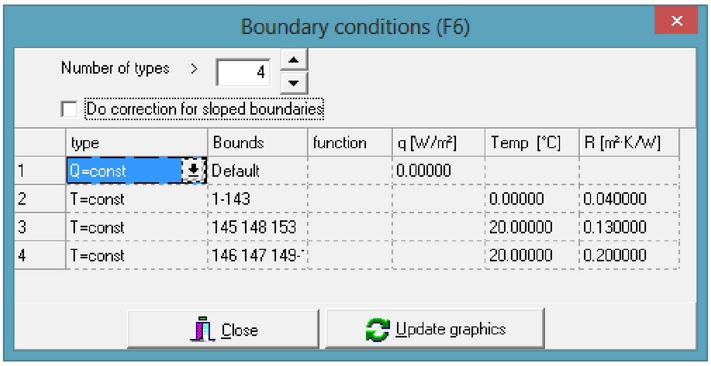
Left: HEAT2 7. Right: HEAT2 8 using polygons.

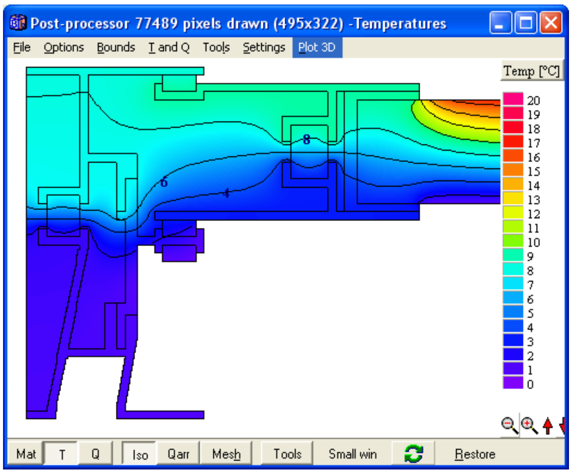
Generated frame cavities:

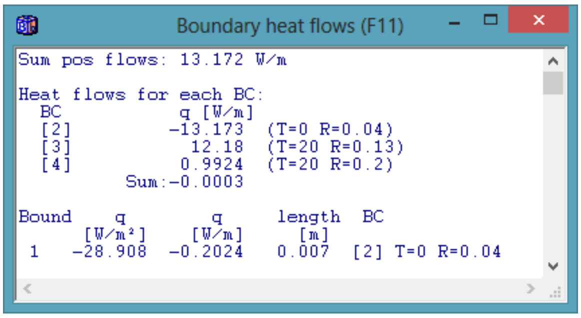


Boundary conditions:

[HEAT2 Version 8): First, turn off "Do correction for sloped boundaries"):







The thermal conductance becomes

$$L^{2D} = 13{,}173/20 = 0{,}6587 \text{ W/(m·K)}$$

and the thermal transmittance becomes

$$U^{f} = (L^{2D} - U_p \cdot b_p)/b_f = (0{,}6587 - 1{,}13086 \cdot 0{,}19)/0{,}095 = 4{,}673 \text{ W/(m}^2\text{·K)}$$

where

$$U_p = 1/(0{,}13+0{,}04+0{,}025/0{,}035) = 1{,}13086 \text{ W/(m}^2\text{·K)}$$

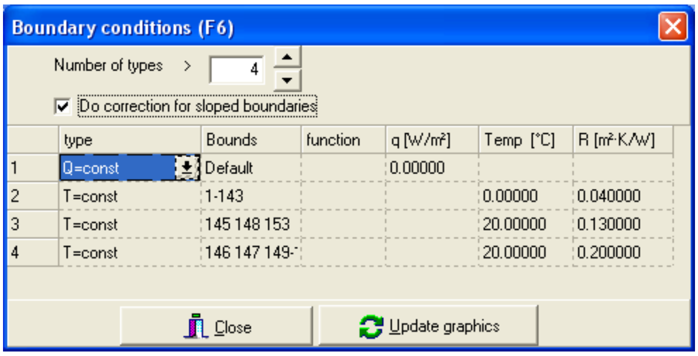
To make this calculation please do as follows:

1. Open file **ISO10077_D6.dat**
2. Start the calculation (press F9)

(***) **Notes on sloping external boundaries:**

There is a need to adjust the thermal resistance of a numerical cell lying at a boundary when a sloping boundary is approximated by steps in order to simulate a boundary condition with a temperature and a surface resistance, or a given heat flux, correctly. HEAT2 v8 is capable of handling this automatically, see chapter 4.4 in [*http://www.buildingphysics.com/manuals/HEAT2_8_update.pdf*](http://www.buildingphysics.com/manuals/HEAT2_8_update.pdf)

With the correction below ("Do correction for sloped boundaries") we get the results below.



The thermal conductance becomes

$$L^{2D} = 13{,}126/20 = 0{,}6563 \text{ W/(m·K)} \quad \text{(0.4\% off ISO 10077-2 value 0,659)}$$

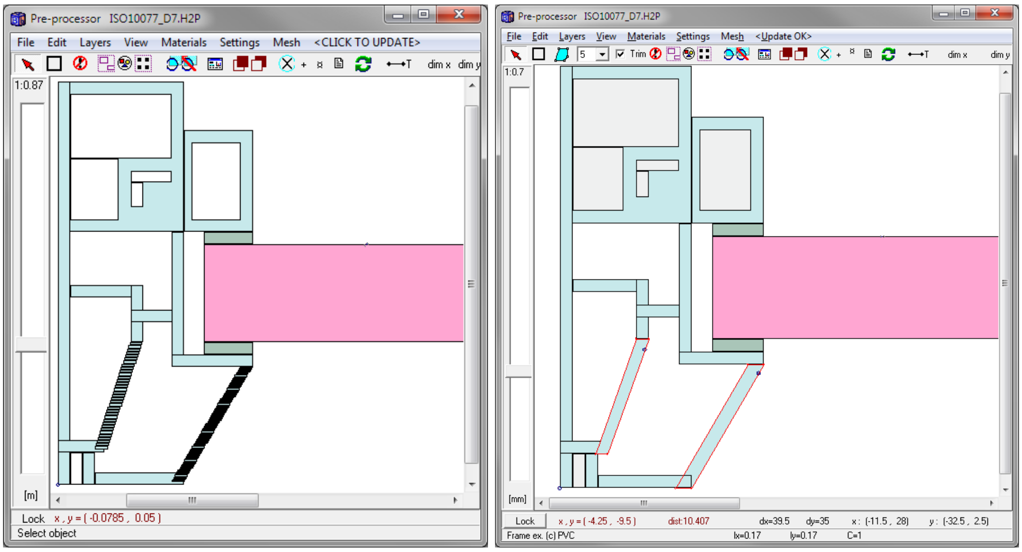
and the thermal transmittance becomes

$$U^{f} = (L^{2D} - U_p \cdot b_p)/b_f = (0{,}6563 - 1{,}13086 \cdot 0{,}19)/0{,}095 = 4{,}647 \text{ W/(m}^2\text{·K)}$$

So we get a thermal transmittance of U=4,647 which compared to the ISO value 4,67 differs by 0.5 %.

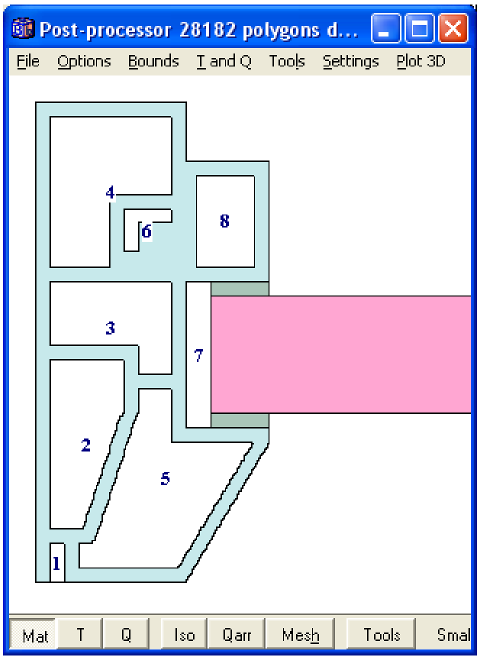
Case D7

Input:



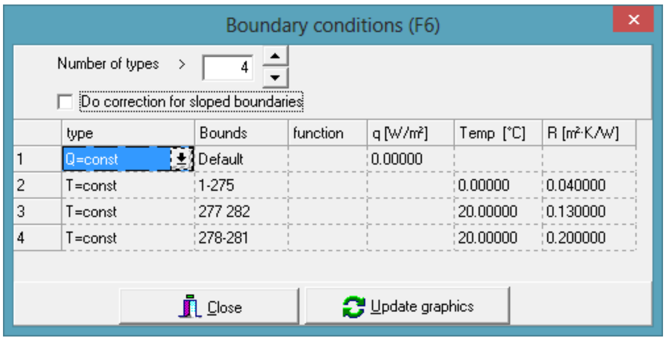
Left: HEAT2 7. Right: HEAT2 8 using polygons.

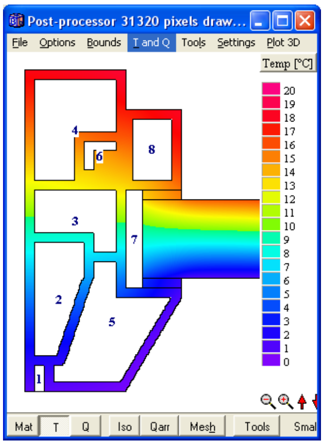
Generated frame cavities:

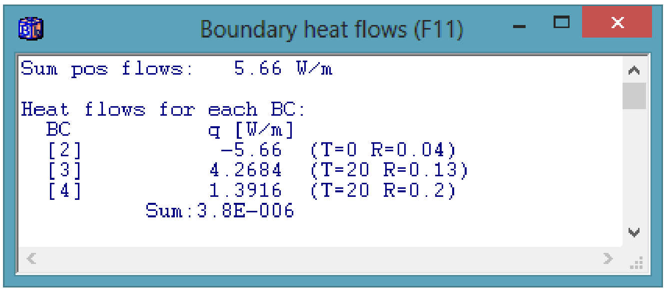


Boundary conditions:

[HEAT2 Version 8): First, turn off “Do correction for sloped boundaries”):







The thermal conductance becomes

$$L^{2D} = 5{,}66/20=0{,}2830\ \mathrm{W/(m \cdot K)}$$

and the thermal transmittance becomes

$$U^{f} = (L^{2D}\text{-}\mathbf{U_p}\cdot\mathbf{b_p})/\mathbf{b_f} = (0{,}2830\text{-}1{,}16861\cdot 0{,}19)/0{,}048=1{,}270\ \mathrm{W/(m^2 \cdot K)}$$

where

$$\mathbf{U_p} = 1/(0{,}13+0{,}04+0{,}024/0{,}035)=1{,}16861\ \mathrm{W/(m^2 \cdot K)}$$

To make this calculation please do as follows:

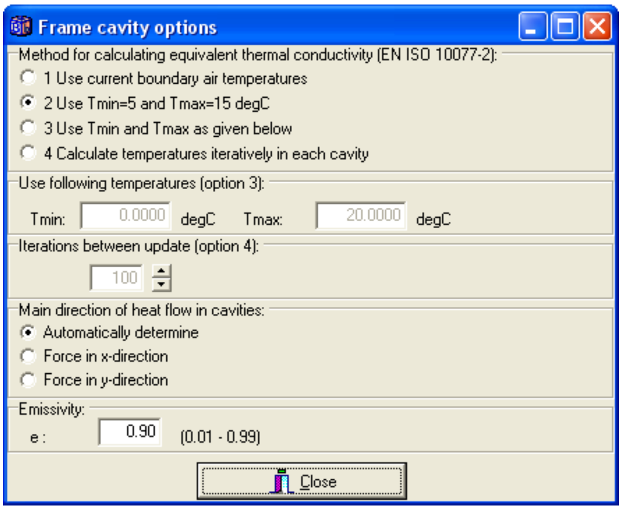
1. Open file **ISO10077_D7.dat**
2. Start the calculation (press F9)

3. Answer yes on the question “Cavity number 1 lies at a boundary. Do you want to use twice the equivalent lambda?”

The calculated equivalent thermal conductivities for each cavity are shown below:

Cavity	Tmax	Tmin	ha	hr	lambda
1	1.7388	0.6173	3.125	2.2591	0.0861
2	8.1271	1.9951	1.3362	2.4042	0.1175
3	12.834	7.0669	1.4973	3.1444	0.0775
4	18.127	12.558	1.2939	3.0094	0.1154
5	6.6104	0.4316	1.3395	2.7467	0.1087
6	15.524	13.411	3.9657	3.2042	0.0452
7	13.562	3.2534	1.5888	2.2387	0.1148
8	17.749	13.651	1.3158	2.8785	0.0797

The standard says that “when no other information is available, use Tm= 283 K”. If we change the option from the default “4 Calculate temperatures iteratively in each cavity” to “2 Use Tmin= 5 and Tmax=15” we get Tm=283.



Cavity	Tmax	Tmin	ha	hr	lambda
1	1.7397	0.6177	3.125	2.4926	0.0899
2	8.1267	1.9959	1.57	2.5431	0.1292
3	12.833	7.0662	1.57	3.1566	0.0789
4	18.126	12.557	1.57	2.8548	0.1186
5	6.6098	0.4317	1.57	2.9542	0.1204
6	15.524	13.41	3.9657	3.0675	0.0443
7	13.561	3.2531	1.57	2.2846	0.1156
8	17.749	13.65	1.57	2.7205	0.0815

The thermal conductance becomes

$$L^{2D} = 5{,}6864/20=0{,}2843 \text{ W/(m·K)}$$

and the thermal transmittance becomes

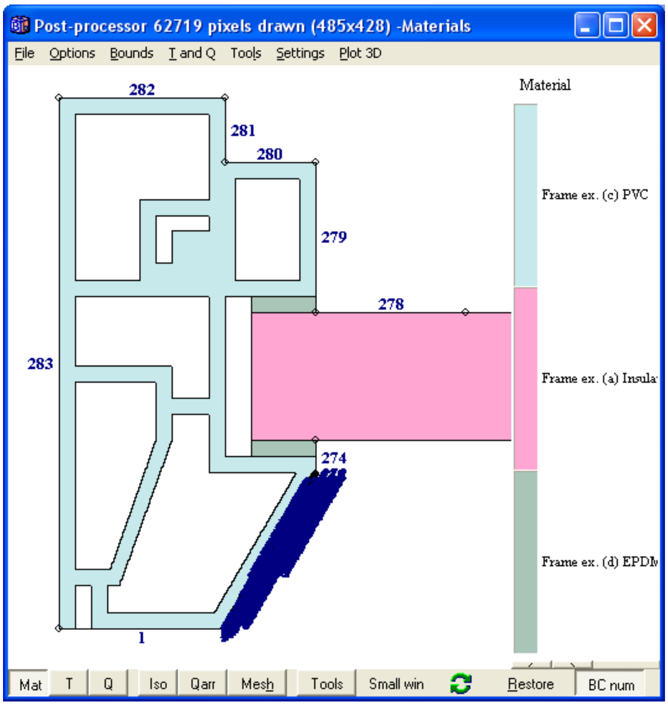
$$U^{f} = (L^{2D}\text{-}U_p \cdot b_p)/b_f = (0{,}2843\text{-}1{,}16861 \cdot 0{,}19)/0{,}048=1{,}298 \text{ W/(m}^2\text{·K)}$$

(***) **Notes on sloping external boundaries:**

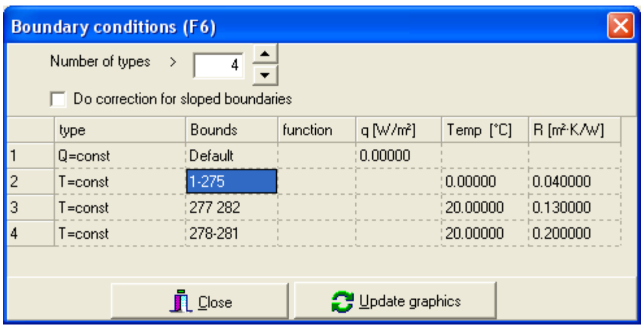
There is a need to adjust the thermal resistance of a numerical cell lying at a boundary when a sloping boundary is approximated by steps in order to simulate a boundary condition with a temperature and a surface resistance, or a given heat flux, correctly. HEAT2 v8 is capable of handling this automatically, see chapter 4.4 in http://www.buildingphysics.com/manuals/HEAT2_8_update.pdf

We need to make this correction for boundaries 2-273, see picture below. In this case, we cannot use the automatic option "Do correction for sloped boundaries", since HEAT2 v8 will identify sloping boundaries for number 2-273 (which is correct) but also for number 278-281 (which is not correct). (The automatically identified boundaries for correction are by the way shown in the log, menu option F12 in HEAT2 v8.)

Therefore, we will make this correction by hand for boundaries 2-273 as described below.

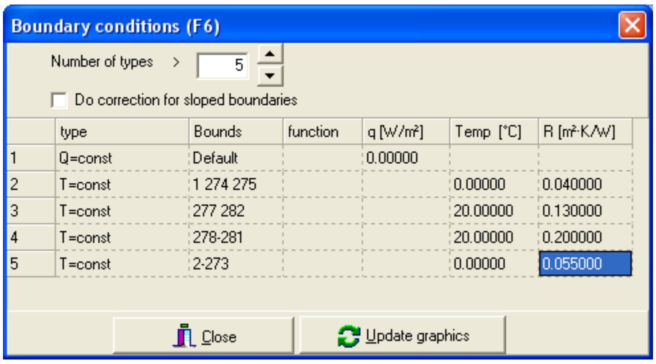


The original boundary conditions are



	type	Bounds	function	q [W/m²]	Temp [°C]	R [m²·K/W]
1	Q=const	Default		0.00000		
2	T=const	1-275			0.00000	0.040000
3	T=const	277 282			20.00000	0.130000
4	T=const	278-281			20.00000	0.200000

The new corrected boundary conditions should be (see file ISO10077_D7_CorrectedBC.dat):



Here, we define a new BC type(5) and use the corrected boundary resistance which is calculated using the total width (w=17 mm) and height (h=29 mm) of the steps 2-273. The correction factor is $(w+h)/\sqrt{w^2+h^2}$ *= 1,368. The corrected boundary resistance is then 1,368x0.04=0.055.*

The calculated thermal conductance becomes then

$$L^{2D} = 5{,}6535/20 = 0{,}2827 \text{ W/(m·K)} \quad \text{(0,8\% off ISO 10077-2 value 0,285)}$$

and the thermal transmittance becomes

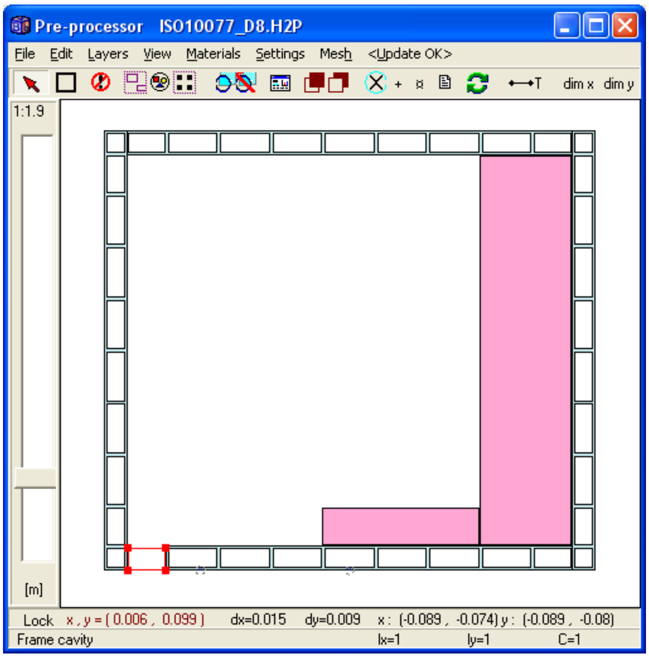
$$U^f = (L^{2D} - U_p \cdot b_p)/b_f = (0{,}2827 - 1{,}16861 \cdot 0{,}19)/0{,}048 = 1{,}263 \text{ W/(m}^2\text{·K)}$$

So we get a thermal transmittance of U=1.263 which compared to the ISO value 1.31 differs by 3,6%.

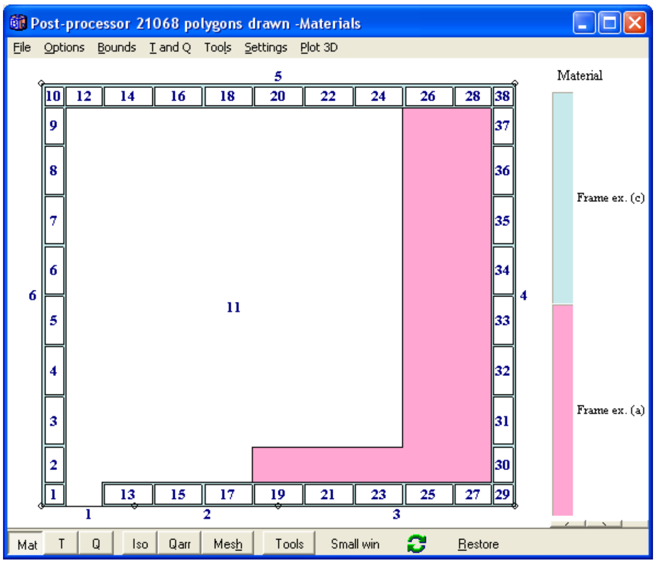
Note: The difference for the heat flow using correction or not, is only about 0.1% (0,2830/0,2827) in this case due to the low boundary resistance (0.04). However, if the thermal boundary resistance increases, the difference will increase. If we e.g. would have change the external and internal boundary conditions (using R=0.13 for the sloping boundaries), the difference of the heat flow would have been 0.2-0.3% instead.

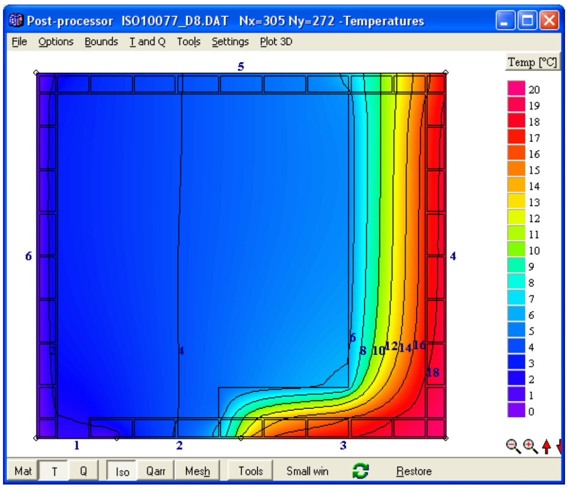
Case D8

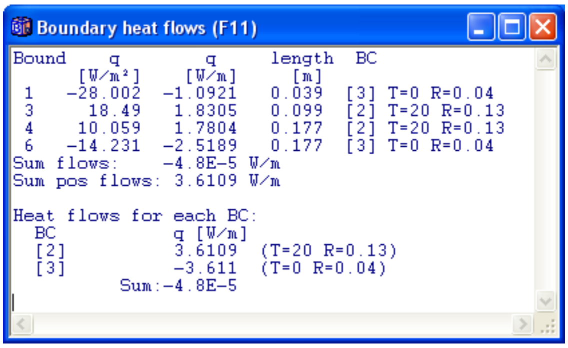
Input:



Generated frame cavities:






Boundary heat flows (F11)

```
Bound      q         q      length   BC
        [W/m²]     [W/m]     [m]
 1    -28.002   -1.0921    0.039   [3] T=0 R=0.04
 3     18.49     1.8305    0.099   [2] T=20 R=0.13
 4     10.059    1.7804    0.177   [2] T=20 R=0.13
 6    -14.231   -2.5189    0.177   [3] T=0 R=0.04
Sum flows:      -4.8E-5 W/m
Sum pos flows:  3.6109 W/m

Heat flows for each BC:
  BC                q [W/m]
  [2]               3.6109   (T=20 R=0.13)
  [3]              -3.611    (T=0 R=0.04)
           Sum:-4.8E-5
```

The thermal conductance becomes

$$\boldsymbol{L}^{2D} = 3{,}6109/20=0{,}1805\ \text{W/(m·K)}$$

and the thermal transmittance becomes

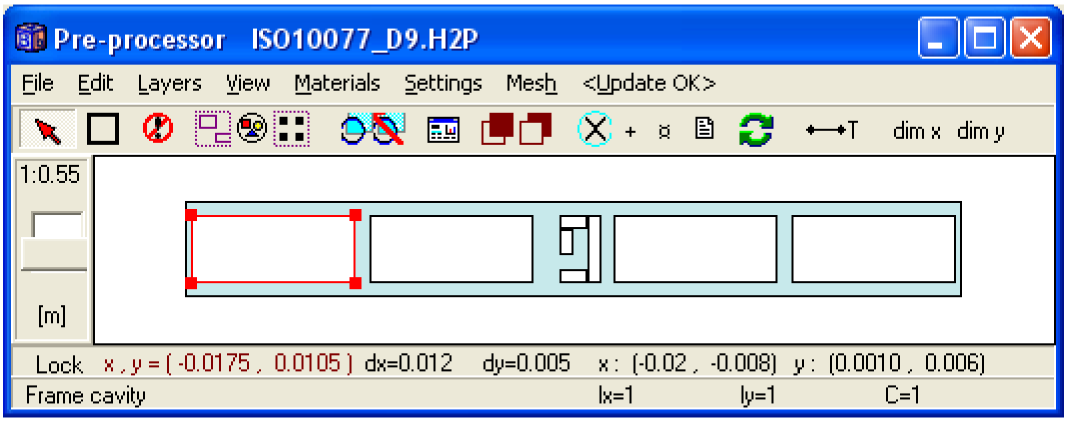
$$\boldsymbol{U}^{f} = \boldsymbol{L}^{2D}/\mathbf{b}_{sb} = 0{,}1805/0{,}177=1{,}020\ \text{W/(m}^2\text{·K)}$$

To make this calculation please do as follows:

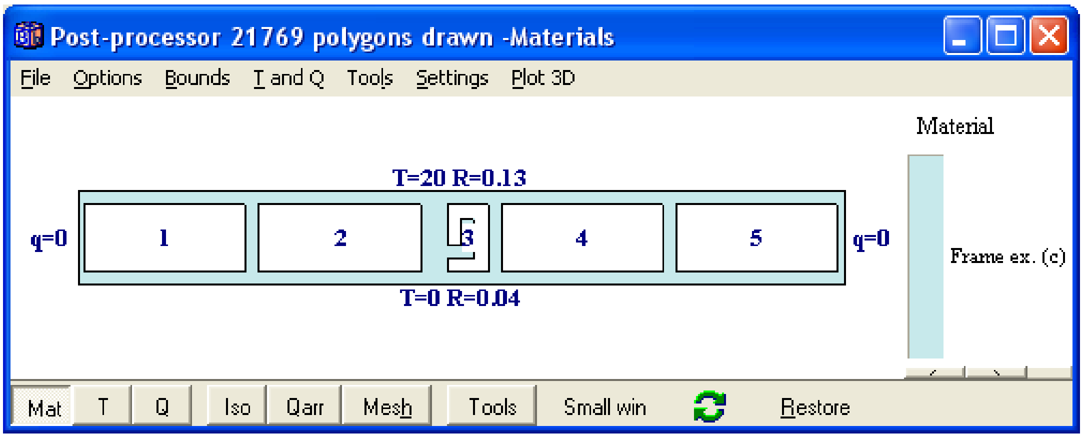
1. Open file **ISO10077_D8.dat**
2. Start the calculation (press F9)
3. Answer yes on the question “Cavity number 1 lies at a boundary. Do you want to use twice the equivalent lambda?”

Case D9

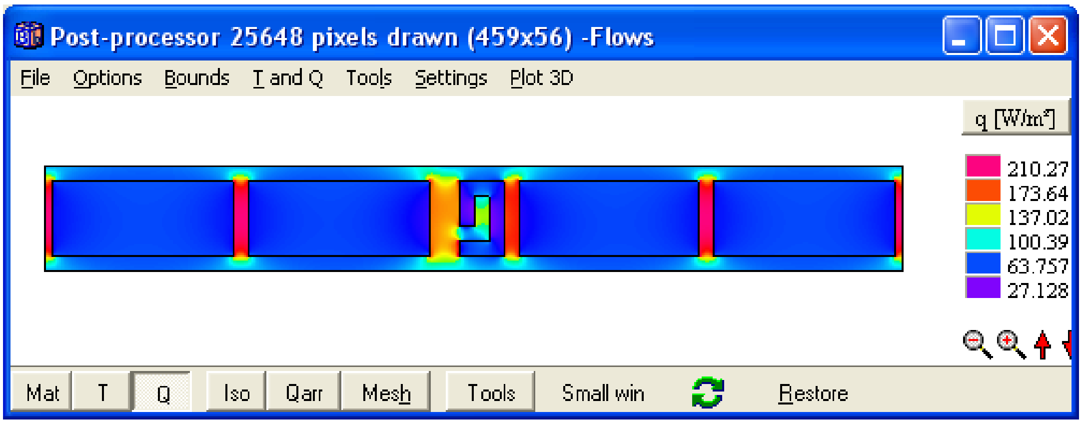
Input:

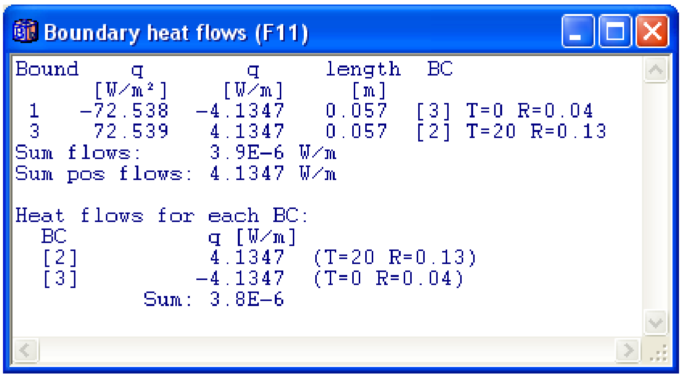


Generated frame cavities:



Calculated heat flows:





```
Boundary heat flows (F11)
Bound     q          q       length   BC
       [W/m²]      [W/m]      [m]
 1    -72.538   -4.1347    0.057   [3] T=0 R=0.04
 3     72.539    4.1347    0.057   [2] T=20 R=0.13
Sum flows:       3.9E-6 W/m
Sum pos flows:   4.1347 W/m

Heat flows for each BC:
  BC              q [W/m]
  [2]            4.1347   (T=20 R=0.13)
  [3]           -4.1347   (T=0 R=0.04)
          Sum:   3.8E-6
```

The thermal conductance becomes

$$L^{2D} = 4{,}1347/20=0{,}2067 \text{ W/(m·K)}$$

and the thermal transmittance becomes

$$U^{f} = L^{2D}/\mathbf{b} = 0{,}2067/0{,}057=3{,}627 \text{ W/(m}^2\text{·K)}$$

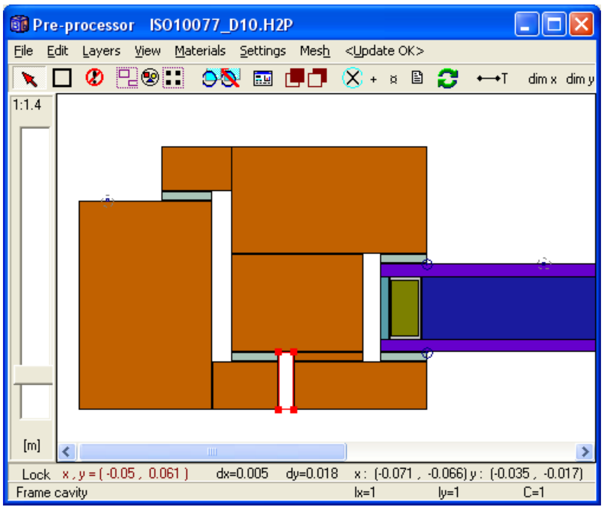
To make this calculation please do as follows:

1. Open file **ISO10077_D9.dat**

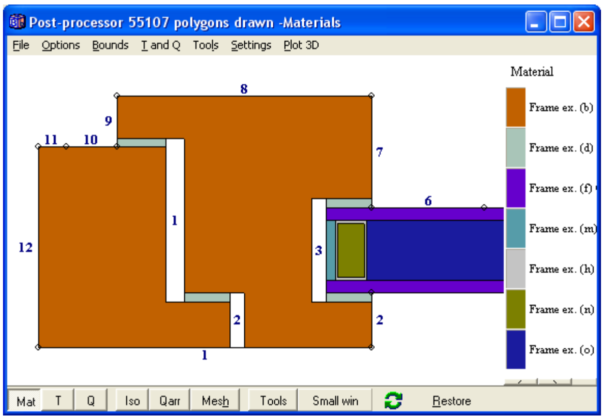
2. Start the calculation (press F9)

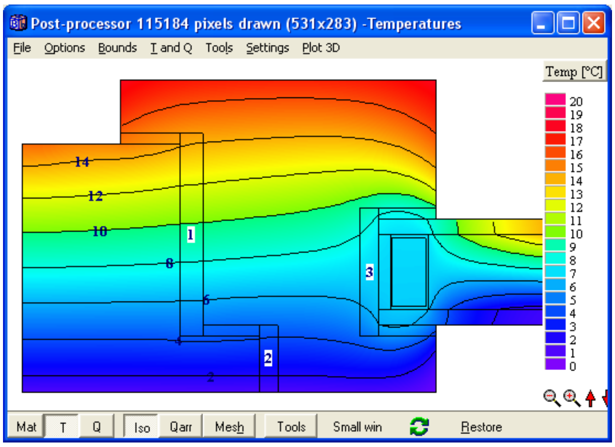
Case D10

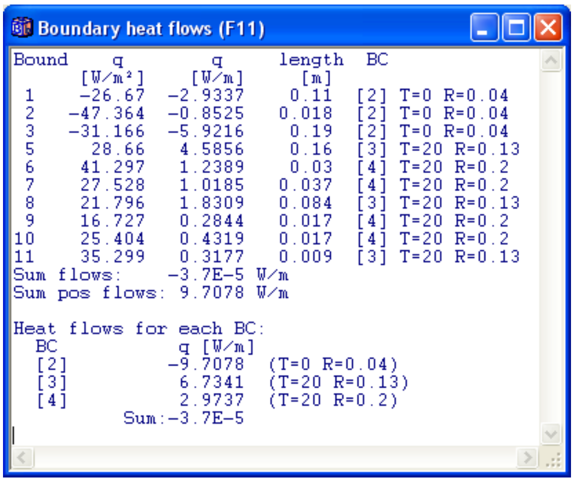
Input:



Generated frame cavities:







```
Boundary heat flows (F11)
Bound      q          q       length   BC
        [W/m²]      [W/m]      [m]
 1     -26.67    -2.9337     0.11   [2] T=0 R=0.04
 2     -47.364   -0.8525    0.018   [2] T=0 R=0.04
 3     -31.166   -5.9216     0.19   [2] T=0 R=0.04
 5      28.66     4.5856     0.16   [3] T=20 R=0.13
 6      41.297    1.2389     0.03   [4] T=20 R=0.2
 7      27.528    1.0185    0.037   [4] T=20 R=0.2
 8      21.796    1.8309    0.084   [3] T=20 R=0.13
 9      16.727    0.2844    0.017   [4] T=20 R=0.2
10      25.404    0.4319    0.017   [4] T=20 R=0.2
11      35.299    0.3177    0.009   [3] T=20 R=0.13
Sum flows:       -3.7E-5 W/m
Sum pos flows:  9.7078 W/m

Heat flows for each BC:
  BC                q [W/m]
  [2]             -9.7078   (T=0 R=0.04)
  [3]              6.7341   (T=20 R=0.13)
  [4]              2.9737   (T=20 R=0.2)
           Sum:-3.7E-5
```

The thermal conductance becomes

$$L_{\Psi}^{2D} = 9{,}7078/20=0{,}4854 \text{ W/(m·K)}$$

and the linear thermal transmittance Ψ becomes

$$\Psi = L_{\Psi}^{2D} - U_f \cdot b_f - U_g \cdot b_g = 0{,}4854 - 1{,}361 \cdot 0.11 - 1{,}3051 \cdot 0{,}19 = 0{,}0877 \text{ W/(m·K)}$$

where U_f is taken from case D4 and

$$U_g = 1/(0{,}13+0{,}04+0{,}020/0{,}033+2 \cdot 0{,}004/1)=1{,}3051 \text{ W/(m}^2\text{·K)}$$

To make this calculation please do as follows:

1. Open file **ISO10077_D10.dat**
2. Start the calculation (press F9)
3. Answer yes on the question “Cavity number 2 lies at a boundary. Do you want to use twice the equivalent lambda?”