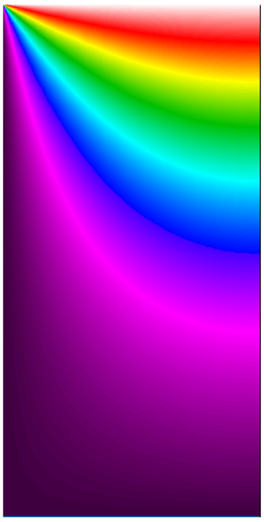
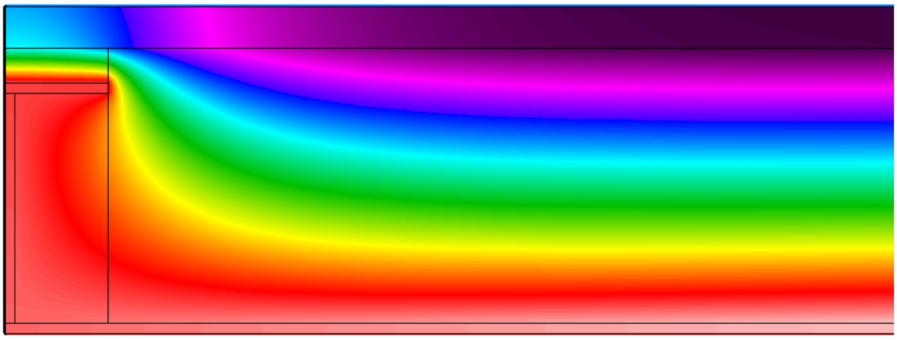
Therm 6.3 validation according to EN ISO 10211:2007





Therm 6.3 validation according to NBN EN ISO 10211:2007

eneral considerations and requirements for validation of calculation methods according to NBN EN ISO 10211:2007

According to NBN EN ISO 10211:2007 - Annex A, the numerical method has to meet the following requirements to be considered a high precision calculation method:

a) the method shall provide temperatures and heat flows
b) the extent of subdivision of the object is not "method defined" but "user defined". Therefore, in the test reference cases, the method being validated shall be able to calculate temperatures and heat flows at locations other than those listed.
c) For an increasing number of subdivisions, the solution of the method being validated shall converge to the analytical solution, if such a solution exists.
d) the number of subdivisions shall be determined as follows: the sum of the absolute values of all the heat flows entering the object is calculated twice, for *n* nodes and for *2n* nodes. The difference between these two results shall not exceed 1%. If not, further subdivisions shall be made until this criterion is met.
e) If the system solution technique is iterative, the iteration shall continue until the sum of all heat flows (positive and negative) entering the object, divided by half the sum of the absolute values of all these heat flows, is less than 0,0001.

The subdivision of a model in Therm 6.3 is controlled by two parameters: by the "Quad Tree Mesh Parameter" which relates to the maximum size of the initial subdivision, and the "Maximum % Error Energy Norm" for iterative calculations that sets a threshold for the iteration to further divide non conforming elements.

The first parameter will relate to the maximum size, but does not allow for exact dimensioning of the subdivision. The larger the number entered, the smaller the elements of the initial subdivision will be. This parameter can be varied between 3 and 12, with standard setting of 6. The second parameter sets a threshold for the error estimator. For each node, this error estimator checks convergence of the result according to the "Maximum % Error Energy Norm". For those elements that do not yet conform, the grid is then refined and a new calculation is started.

Since the user has no exact control over the dimensions of the subdivision, the model has to be subdivided by the user when looking for temperatures and heat flows at specific locations.

NBN EN ISO 10211:2007 - Annex A provides two test cases for a two dimensional calculation method to be classified as a steady-state high precision method.

Case 1:

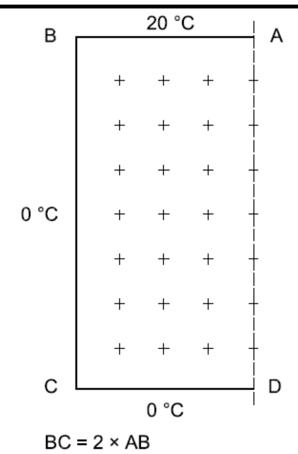
This case consists of a model of a half square column with known surface temperatures. Only these surface temperatures are given. The other variables are implied, or have to be chosen:

- thermal conductivity λ = 1 W/mK

- surface resistance: Rs = 0 m²K/W
- geometry: BA = 200mm; BC = 400mm

As for the surface resistance, this has to be defined in Therm as part of the boundary condition in the form of a film coefficient. Therm limits the range of this film coefficient to between 0 and 99999. In order to approximate Rs = 0 m²K/W, the highest possible film coefficient is used: 99999 W/m²K.

The analytical solution at 28 points of an equidistant grid is given. The difference between the temperatures calculated by the method being validated and the temperatures listed shall not exceed 0,1K.



Analytical solution at grid nodes (°C)			
9,7	13,4	14,7	15,1
5,3	8,6	10,3	10,8
3,2	5,6	7,0	7,5
2,0	3,6	4,7	5,0
1,3	2,3	3,0	3,2
0,7	1,4	1,8	1,9
0,3	0,6	0,8	0,9

Figure 1: ISO 10211:2007 illustration of validation case 1

The model was drawn as a grid of elements, each 50mmx50mm, 4 elements wide and 8 elements high. This to ensure that Therm would calculate the temperatures at the corners of these elements.

The model is calculated using an iterative method. The default Quad Tree Mesh Parameter is set to 6 and the Maximum % Error Energy Norm is set to 10%. When calculating the model with these parameters, the resulting temperatures lie well within the tolerance of 0,1K.

To evaluate the requirements c to e, the Quad Tree Mesh Parameter is set to its standard value of 6. Requirement d specifies that with doubling number of nodes, the sum of the absolute terms of the heat flows should not differ more than 1%. Because Therm does not allow the user to exactly choose the number of nodes, an approximation is made using het Maximum % Error Energy Norm, as shown in figure 2.

In all cases, the temperature difference stays well below 0,1K.

Figure 3 shows the fulfillment of the requirements c to e. The calculated temperatures and heat flows converge, the difference as specified in d stays under 1%, and the requirement e for an iterative process stays well below the required 0,0001.

Quad Tree Mesh Parameter			6		6		6		6		6	
Max. % Error Energy Norm			10		5,35		3,9		2,96		2,5	
# nodes			936		1923		3981		8177		12009	
# elements			901		2015		4474		9327		13772	
coördinate		EN10211										
x(mm)	y(mm)	T [°C]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]
50	50	9,7	9,66E+00	0,04	9,66E+00	0,04	9,66E+00	0,04	9,66E+00	0,04	9,66E+00	0,04
50	100	5,3	5,24E+00	0,06	5,26E+00	0,04	5,26E+00	0,04	5,25E+00	0,05	5,25E+00	0,05
50	150	3,2	3,18E+00	0,02	3,19E+00	0,01	3,19E+00	0,01	3,19E+00	0,01	3,19E+00	0,01
50	200	2	2,01E+00	0,01	2,01E+00	0,01	2,01E+00	0,01	2,01E+00	0,01	2,01E+00	0,01
50	250	1,3	1,26E+00	0,04	1,26E+00	0,04	1,26E+00	0,04	1,26E+00	0,04	1,26E+00	0,04
50	300	0,7	7,39E-01	0,04	7,39E-01	0,04	7,39E-01	0,04	7,40E-01	0,04	7,40E-01	0,04
50	350	0,3	3,41E-01	0,04	3,42E-01	0,04	3,42E-01	0,04	3,44E-01	0,04	3,42E-01	0,04
100	50	13,4	1,34E+01	0,01	1,34E+01	0,03	1,34E+01	0,02	1,34E+01	0,03	1,34E+01	0,02
100	100	8,6	8,64E+00	0,04	8,64E+00	0,04	8,64E+00	0,04	8,64E+00	0,04	8,64E+00	0,04
100	150	5,6	5,61E+00	0,01	5,61E+00	0,01	5,61E+00	0,01	5,61E+00	0,01	5,61E+00	0,01
100	200	3,6	3,64E+00	0,04	3,64E+00	0,04	3,64E+00	0,04	3,64E+00	0,04	3,64E+00	0,04
100	250	2,3	2,31E+00	0,01	2,31E+00	0,01	2,31E+00	0,01	2,31E+00	0,01	2,31E+00	0,01
100	300	1,4	1,36E+00	0,04	1,36E+00	0,04	1,36E+00	0,04	1,36E+00	0,04	1,36E+00	0,04
100	350	0,6	6,29E-01	0,03	6,29E-01	0,03	6,29E-01	0,03	6,30E-01	0,03	6,30E-01	0,03
150	50	14,7	1,47E+01	0,04	1,47E+01	0,03	1,47E+01	0,03	1,47E+01	0,03	1,47E+01	0,03
150	100	10,3	1,03E+01	0,02	1,03E+01	0,02	1,03E+01	0,02	1,03E+01	0,02	1,03E+01	0,02
150	150	7	7,02E+00	0,02	7,02E+00	0,02	7,02E+00	0,02	7,01E+00	0,01	7,01E+00	0,01
150	200	4,7	4,66E+00	0,04	4,66E+00	0,04	4,65E+00	0,05	4,66E+00	0,04	4,66E+00	0,04
150	250	3	2,98E+00	0,02	2,98E+00	0,02	2,99E+00	0,01	2,99E+00	0,01	2,99E+00	0,01
150	300	1,8	1,77E+00	0,03	1,77E+00	0,03	1,77E+00	0,03	1,77E+00	0,03	1,77E+00	0,03
150	350	0,8	8,19E-01	0,02	8,19E-01	0,02	8,20E-01	0,02	8,20E-01	0,02	8,20E-01	0,02
200	50	15,1	1,51E+01	0,01	1,51E+01	0,01	1,51E+01	0,01	1,51E+01	0,01	1,51E+01	0,01
200	100	10,8	1,08E+01	0,02	1,08E+01	0,02	1,08E+01	0,01	1,08E+01	0,01	1,08E+01	0,01
200	150	7,5	7,47E+00	0,03	7,47E+00	0,03	7,47E+00	0,03	7,46E+00	0,04	7,47E+00	0,03
200	200	5	5,00E+00	0,00	5,00E+00	0,00	5,00E+00	0,00	5,00E+00	0,00	5,00E+00	0,00
200	250	3,2	3,22E+00	0,02	3,22E+00	0,02	3,22E+00	0,02	3,22E+00	0,02	3,22E+00	0,02
200	300	1,9	1,91E+00	0,01	1,91E+00	0,01	1,91E+00	0,01	1,91E+00	0,01	1,91E+00	0,01
200	350	0,9	8,86E-01	0,01	8,86E-01	0,01	8,86E-01	0,01	8,87E-01	0,01	8,87E-01	0,01
Maximum ΔT [K]				0,06		0,04		0,05		0,05		0,05
mean ΔT [K]				0,03		0,03		0,02		0,03		0,02

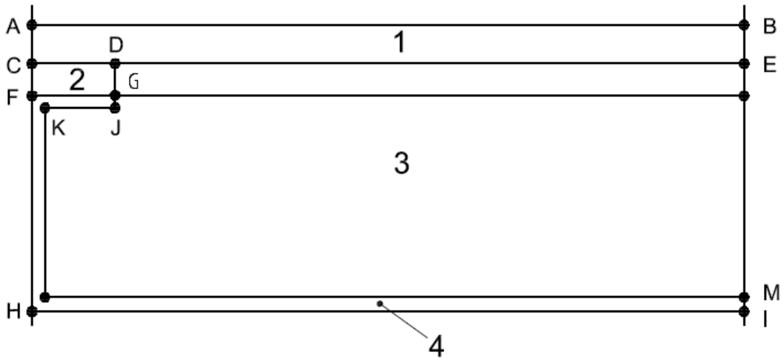
Figure 2: Calculation results for different Maximum % Error Energy Norm.

Quad Tree Mesh Parameter	6	6	6	6	6
Max. % Error Energy Norm	10	5,35	3,9	2,96	2,5
# nodes	936	1923	3981	8177	12009
# elements	901	2015	4474	9327	13772
Φ_{out} [W]	127,877	126,9948	126,7538	126,6615	126,6506
Φ_{in} [W]	127,8765	126,9949	126,7538	126,6615	126,6499
$\lvert\Phi_{out}\rvert+\lvert\Phi_{in}\rvert$	255,7536	253,9898	253,5076	253,323	253,3005
difference according to d)		0,69%	0,19%	0,07%	0,01%
$(\lvert\Phi_{out}\rvert+\lvert\Phi_{in}\rvert)/2$	127,8768	126,9949	126,7538	126,6615	126,6503
$\Phi_{in} - \Phi_{out}$	5,00E-04	1,10E-04	7,03E-05	3,97E-05	6,91E-04
$2(\Phi_{in} - \Phi_{out})/(\lvert\Phi_{out}\rvert+\lvert\Phi_{in}\rvert)$	3,91E-06	8,62E-07	5,55E-07	3,13E-07	5,46E-06

Figure 3: Calculation of the convergence and error of the calculation for varying Maximum % Error Energy Norm.

Case 2

For validation case 2, part of a wall construction is calculated. All dimensions and boundary conditions are specified.



Dimensions mm	Thermal conductivity W/(m·K)	Boundary conditions
AB = 500	1: 1,15	AB: 0 °C with R_{se} = 0,06 m²·K/W
AC = 6	2: 0,12	HI: 20 °C with R_{si} = 0,11 m²·K/W
CD = 15	3: 0,029	
CF = 5	4: 230	
EM = 40		
GJ = 1,5		
IM = 1,5		
FG – KJ = 1,5		

Figure 4: ISO 10211:2007 illustration of validation case 2

This model is calculated, and the result has to fulfill following requirements:

- The calculated temperatures at certain points as specified in the validation case should not differ more than 0,1K from the given temperatures.
- The calculated heat flow should not differ more than 0,1 W/mK from the given heat flow.

Temperatures °C		
A: 7,1		B: 0,8
C: 7,9	D: 6,3	E: 0,8
F: 16,4	G: 16,3	
H: 16,8		I: 18,3
Total heat flow rate: 9,5 W/m		

Figure 5: ISO 10211:2007 illustration of the solution of validation case 2

The model is calculated iteratively, with a Quad Tree Mesh Parameter set to 6. The Maximum % Error Energy Norm is varied to approximate doubling the number of nodes, in order to evaluate the extra requirements c to e. Since all points where the temperature is to be calculated are present in the geometrical model, no extra points have to be drawn.

Therm outputs the calculated heat flow over the whole model as a unity of three parts: a U-factor [W/m²K], a length [m] and a temperature difference [K]. Multiplying these three results gives the heat flow [W/m].

Figure 6 shows the results of the calculations, which all lie well within the requested 0,1K difference in temperature and 0,1W/m difference in heat flow.

Figure 7 illustrates conformity with requirements c to e.

Quad Tree Mesh Parameter		6		6		6		6	
Max. % Error Energy Norm		10		6		3,62		2	
# nodes		227		422		1106		3607	
# elements		195		401		1124		3703	
Point	EN10211 T [°C]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]
A	7,1	7,10	0,00	7,07	0,03	7,06	0,04	7,06	0,04
C	7,9	7,91	0,01	7,90	0,00	7,90	0,00	7,90	0,00
F	16,4	16,40	0,00	16,40	0,00	16,41	0,01	16,41	0,01
H	16,8	16,75	0,05	16,76	0,04	16,77	0,03	16,77	0,03
D	6,3	6,29	0,01	6,28	0,02	6,28	0,02	6,27	0,03
G	16,3	16,32	0,02	16,33	0,03	16,33	0,03	16,33	0,03
B	0,8	0,76	0,04	0,76	0,04	0,76	0,04	0,76	0,04
E	0,8	0,83	0,03	0,83	0,03	0,83	0,03	0,83	0,03
I	18,3	18,33	0,03	18,33	0,03	18,33	0,03	18,33	0,03
Maximum ΔT [K]			0,05		0,04		0,04		0,04
mean ΔT [K]			0,02		0,02		0,03		0,03
Heat flow	EN10211 W/m	Φ [W/m]	ΔΦ [W/m]	Φ [W/m]	ΔΦ [W/m]	Φ [W/m]	ΔΦ [W/m]	Φ [W/m]	ΔΦ [W/m]
	9,5	9,526	0,026	9,505	0,005	9,496	0,004	9,493	0,007

Figure 6: temperatures and heat flow of the model calculated with different Maximum % Error Energy Norm.

Quad Tree Mesh Parameter	6	6	6	6
Max. % Error Energy Norm	10	6	3,62	2
# nodes	227	422	1106	3607
# elements	195	401	1124	3703
Φ_{out} [W]	9,525761	9,505003	9,496054	9,493053
Φ_{in} [W]	9,52579	9,504952	9,496047	9,49307
$\lvert\Phi_{out}\rvert+\lvert\Phi_{in}\rvert$	19,05	19,01	18,99	18,99
difference according to d)		0,22%	0,09%	0,03%
$(\lvert\Phi_{out}\rvert+\lvert\Phi_{in}\rvert)/2$	9,5257755	9,504978	9,496051	9,493062
$\Phi_{in} - \Phi_{out}$	2,90E-05	5,10E-05	7,00E-06	1,70E-05
$2(\Phi_{in} - \Phi_{out})/(\lvert\Phi_{out}\rvert+\lvert\Phi_{in}\rvert)$	3,04E-06	5,37E-06	7,37E-07	1,79E-06

Figure 7: Calculation of the convergence and error of the calculation for varying Maximum % Error Energy Norm.

Conclusion

Therm 6.3 complies with all requirements of the ISO 10211:2007 Annex A to be considered a two dimensional high precision calculation method.

For a ‘Quad Tree Mesh Parameter’ set to 6 and a ‘Maximum % Error Energy Norm’ set to 10% under Options/Preferences/Therm file options (these are the standard settings) the calculation lies within the required precision, fot higher Quad Tree Mesh Parameters values and lower Maximum % Error Energy Norm values, the result will further converge to the ‘optimal solution’.

Berchem, April 2011

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