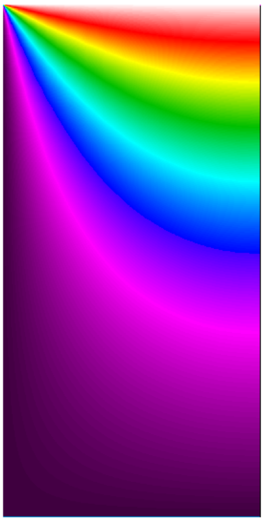
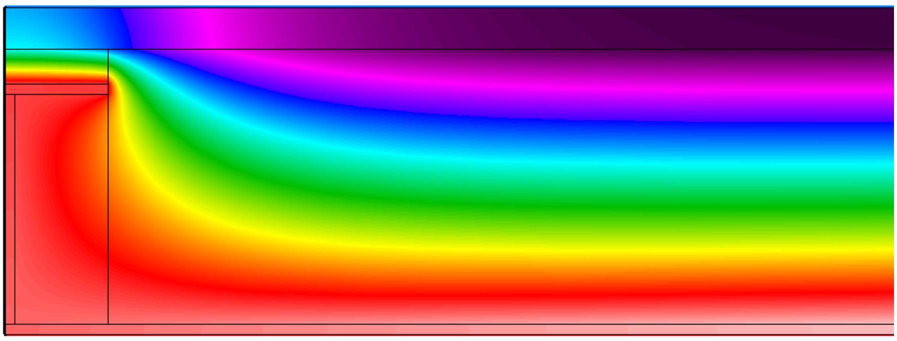
Therm 7.4 validation according to EN ISO 10211:2007





Therm 7.4 validation according to NBN EN ISO 10211:2007

General 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 7.4 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.

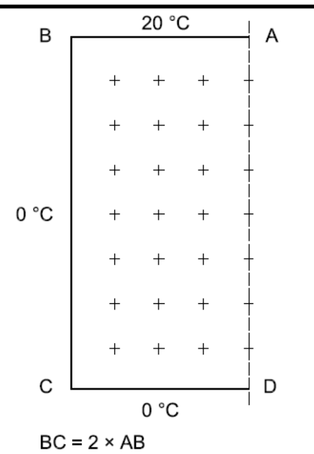
Case 1:

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. The following variables are chosen:

- thermal conductivity λ = 0,10 W/mK
- 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				9,7		6,34		5,89		5,54		5,4	
	# nodes			1080		1582		2809		2927		3252	
	# elements			1048		1576		2909		3057		3432	
coördinate		EN10211	Node	20		25		30		35		40	
x(mm)	y(mm)	T [°C]	nr	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]
50	50	9,7	41,0	9,6600	0,0400	9,6479	0,0121	9,6591	0,0113	9,6596	0,0005	9,6590	0,0006
50	100	5,3	87,0	5,2429	0,0571	5,2459	0,0030	5,2565	0,0106	5,2576	0,0011	5,2576	0,0000
50	150	3,2	149,0	3,1830	0,0170	3,1836	0,0006	3,1854	0,0018	3,1857	0,0002	3,1864	0,0008
50	200	2,0	217,0	2,0110	0,0110	2,0112	0,0002	2,0118	0,0005	2,0118	0,0000	2,0120	0,0003
50	250	1,3	285,0	1,2607	0,0393	1,2608	0,0001	1,2610	0,0002	1,2610	0,0000	1,2611	0,0001
50	300	0,7	353,0	0,7387	0,0387	0,7387	0,0000	0,7388	0,0001	0,7388	0,0000	0,7388	0,0001
50	350	0,3	421,0	0,3414	0,0414	0,3414	0,0000	0,3414	0,0000	0,3414	0,0000	0,3414	0,0000
100	50	13,4	83,0	13,3908	0,0092	13,3895	0,0013	13,3767	0,0128	13,3770	0,0003	13,3768	0,0002
100	100	8,6	145,0	8,6426	0,0426	8,6430	0,0004	8,6426	0,0004	8,6417	0,0009	8,6421	0,0004
100	150	5,6	213,0	5,6067	0,0067	5,6071	0,0005	5,6080	0,0008	5,6079	0,0001	5,6084	0,0004
100	200	3,6	281,0	3,6379	0,0379	3,6381	0,0003	3,6385	0,0004	3,6385	0,0000	3,6388	0,0003
100	250	2,3	349,0	2,3065	0,0065	2,3067	0,0001	2,3068	0,0002	2,3068	0,0000	2,3070	0,0001
100	300	1,4	417,0	1,3580	0,0420	1,3581	0,0001	1,3582	0,0001	1,3582	0,0000	1,3583	0,0001
100	350	0,6	479,0	0,6288	0,0288	0,6289	0,0000	0,6289	0,0000	0,6289	0,0000	0,6289	0,0000
150	50	14,7	141,0	14,7377	0,0377	14,7375	0,0002	14,7346	0,0029	14,7345	0,0001	14,7344	0,0002
150	100	10,3	209,0	10,3222	0,0221	10,3222	0,0000	10,3203	0,0019	10,3201	0,0002	10,3201	0,0000
150	150	7,0	277,0	7,0161	0,0161	7,0163	0,0002	7,0159	0,0004	7,0157	0,0002	7,0159	0,0002
150	200	4,7	345,0	4,6575	0,0425	4,6577	0,0002	4,6577	0,0000	4,6576	0,0001	4,6578	0,0002
150	250	3,0	413,0	2,9843	0,0157	2,9845	0,0001	2,9845	0,0001	2,9845	0,0000	2,9846	0,0001
150	300	1,8	475,0	1,7655	0,0345	1,7656	0,0001	1,7656	0,0000	1,7656	0,0000	1,7657	0,0001
150	350	0,8	521,0	0,8192	0,0192	0,8192	0,0000	0,8192	0,0000	0,8192	0,0000	0,8193	0,0000
200	50	15,1	205,0	15,0929	0,0071	15,0928	0,0001	15,0912	0,0016	15,0911	0,0001	15,0910	0,0001
200	100	10,8	273,0	10,8180	0,0180	10,8180	0,0000	10,8165	0,0015	10,8163	0,0002	10,8163	0,0000
200	150	7,5	341,0	7,4685	0,0315	7,4687	0,0002	7,4680	0,0007	7,4678	0,0001	7,4680	0,0001
200	200	5,0	409,0	5,0002	0,0002	5,0004	0,0002	5,0002	0,0002	5,0001	0,0001	5,0003	0,0002
200	250	3,2	471,0	3,2173	0,0173	3,2175	0,0001	3,2175	0,0000	3,2174	0,0000	3,2175	0,0001
200	300	1,9	517,0	1,9070	0,0070	1,9071	0,0001	1,9071	0,0000	1,9071	0,0000	1,9072	0,0001
200	350	0,9	547,0	0,8855	0,0145	0,8856	0,0000	0,8856	0,0000	0,8856	0,0000	0,8856	0,0000
	Maximum ΔT [K]				0,0571		0,0121		0,0128		0,0011		0,0008
	mean ΔT [K]				0,0251		0,0007		0,0017		0,0002		0,0002

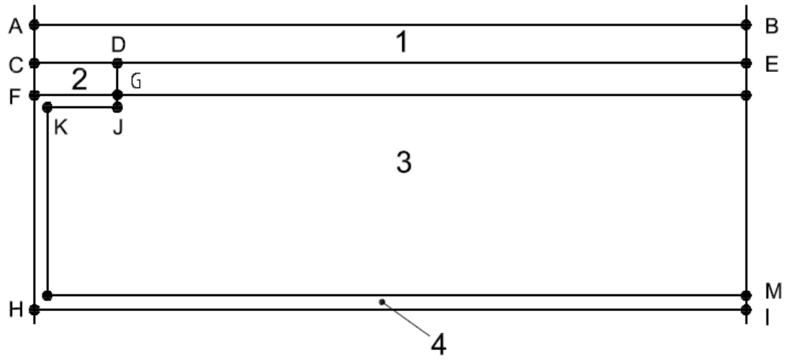
Figure 2: Calculation results for different Maximum % Error Energy Norm.

Quad Tree Mesh Parameter	6	6	6	6	6
Max. % Error Energy Norm	9,7	6,34	5,89	5,54	5,4
# nodes	1080	1582	2809	2927	3252
# elements	1048	1576	2909	3057	3432
Φ_{out} [W]	15,67750	15,63305	15,61369	15,61280	15,61130
Φ_{in} [W]	15,67750	15,63307	15,61372	15,61280	15,61133
$\|\Phi_{out}\|+\|\Phi_{in}\|$	31,355	31,26612	31,22741	31,22561	31,22263
difference according to d)		0,28%	0,12%	0,01%	0,01%
$(\|\Phi_{out}\|+\|\Phi_{in}\|)/2$	15,6775	15,63306	15,61371	15,6128	15,61131
$\Phi_{in} - \Phi_{out}$	3,82E-06	1,66E-05	3,40E-05	3,43E-06	2,91E-05
$2(\Phi_{in} - \Phi_{out})/(\|\Phi_{out}\|+\|\Phi_{in}\|)$	2,44E-07	1,06E-06	2,18E-06	2,20E-07	1,86E-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		6	
Max. % Error Energy Norm				7,78		4,28		2,6		1,52		0,9	
	# nodes			220		409		1018		3461		12531	
	# elements			189		390		1031		3539		12774	
		EN10211	Node	17		22		27		32		37	
	Point	T [°C]	nr	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]	T [°C]	ΔT [K]
	A	7,1	208	7,12	-0,02	7,08	0,02	7,07	0,03	7,06	0,04	7,06	0,05
	C	7,9	219	7,93	-0,03	7,91	-0,01	7,90	0,00	7,90	0,00	7,90	0,03
	F	16,4	207	16,40	0,00	16,41	-0,01	16,41	-0,01	16,41	-0,01	16,41	-0,01
	H	16,8	157	16,75	0,05	16,76	0,04	16,77	0,03	16,77	0,03	16,77	-0,02
	D	6,3	201	6,29	0,01	6,28	0,02	6,28	0,02	6,28	0,02	6,27	0,02
	G	16,3	188	16,32	-0,02	16,33	-0,03	16,33	-0,03	16,33	-0,03	16,33	-0,01
	B	0,8	17	0,76	0,04	0,76	0,04	0,76	0,04	0,76	0,04	0,76	0,00
	E	0,8	11	0,83	-0,03	0,83	-0,03	0,83	-0,03	0,83	-0,03	0,83	0,00
	I	18,3	1	18,33	-0,03	18,33	-0,03	18,33	-0,03	18,33	-0,03	18,33	0,00
	Maximum ΔT [K]				0,05		0,04		0,04		0,04		0,04
	mean ΔT [K]				0,02		0,02		0,03		0,03		0,03
		EN10211											
	Heat flow	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]	Φ [W/m]	ΔΦ [W/m]
		9,5		9,538	-0,038	9,506	-0,006	9,497	0,003	9,493	0,007	9,492	0,008

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

Quad Tree Mesh Parameter	6	6	6	6	6
Max. % Error Energy Norm	7,78	4,28	2,6	1,52	0,90
# nodes	220	409	1018	3461	12531
# elements	189	390	1031	3539	12774
Φ_{out} [W]	9,53787	9,50614	9,49703	9,49329	9,49210
Φ_{in} [W]	9,53790	9,50610	9,49698	9,49329	9,49211
$\|\Phi_{out}\|+\|\Phi_{in}\|$	19,07576	19,01224	18,99401	18,98659	18,98420
difference according to d)		0,33%	0,10%	0,04%	0,01%
$(\|\Phi_{out}\|+\|\Phi_{in}\|)/2$	9,537882	9,506119	9,497004	9,493292	9,492102
$\Phi_{in} - \Phi_{out}$	2,80E-05	3,60E-05	4,60E-05	5,00E-06	8,80E-06
$2(\Phi_{in} - \Phi_{out})/(\|\Phi_{out}\|+\|\Phi_{in}\|)$	2,94E-06	3,79E-06	4,84E-06	5,27E-07	9,27E-07

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

Conclusion

Therm 7.4 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, May 2016

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