[European projects]

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Note: This version P198 of this paper replaces previous versions P152 and P197. The (small) changes of content are:

- **The table on calculation programmes has been updated.**
- **The meaning of the validation column has been clarified.**

All other changes (limited in number) concern minor rephrasing and reformatting.


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM
EN ISO 10211
December 2007
English Version
Thermal bridges in building construction - Heat flows and surface temperatures - Detailed calculations (ISO 10211:2007)

The front page of EN ISO 10211:2007.

Software and atlases for evaluating thermal bridges

Different tools are available for evaluating thermal bridges. This paper provides information on software and atlases that are frequently used in the Member States. The European/International standard EN ISO 10211 is also briefly presented: it establishes the conventions to be followed when modelling thermal bridges, and provides for the validation of software.

1 > Objectives of the paper

As described in Information Paper P064, thermal bridges must be taken into account in the EPB-regulations of most European Member States (MS). The detailed evaluation of the linear thermal transmittance ψ [W/(mK)] or the point thermal transmittance χ [W/K] is one of the options to do this. Specific tools are needed to determine the ψ or χ values. There are two kinds of tools: numerical calculation software and thermal bridge atlases. Numerical calculation should be carried out using validated software and following rules that are usually given in a standard, which in the framework of EPB-regulations is usually the European/International standard EN ISO 10211 *[1]*. In a first section, the present paper will summarize the content of this standard and the rules to be followed for the modelling of thermal bridges. The validation test cases of this standard will then be described. In a second section, a survey of software tools for thermal bridge calculations will be given. Finally, the available atlases used in the different MS will be presented.

This paper is based on an internal ASIEPI survey of the following countries: Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, Norway, Poland, Romania, Spain and the United Kingdom.

2 > The EN ISO 10211 standard for the calculation of thermal bridges and other transmission standards

As mentioned above, most of the EPB-regulations of the MS refer to the standard EN ISO 10211 for the detailed numerical calculation of the linear thermal transmittance of thermal bridges. In this section, we present two aspects of this standard: the modelling rules and the validation test cases. It should be noted that the description given below is only a short summary of the standard and is not intended to be comprehensive. The goal is to outline the procedure for the modelling of a thermal bridge detail in software and to emphasize the need for software validation.

Modelling rules

The first set of important rules are those that concern the dimension of the numerical model. As the goal is to model a part of the whole building including the thermal bridge, cut-off planes must be defined so that the

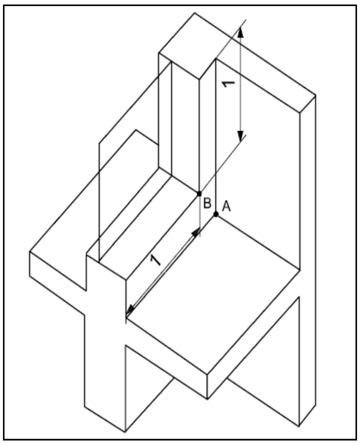
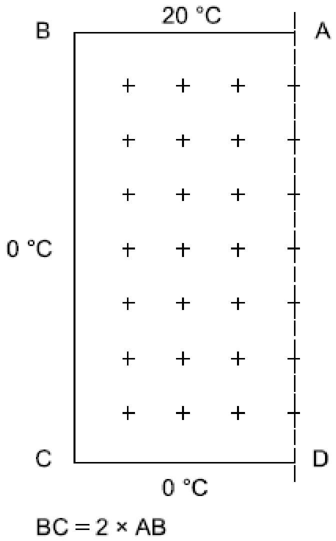


Illustration of the distances of the cut-off planes from the thermal bridge in point B (EN ISO 10211).



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

Test reference case 1 of the annex 1 of the EN ISO 10211.

impact of the thermal bridge is the same as if the entire building was to be directly calculated. EN ISO 10211 *[1]* defines minimum distances between the cut-off planes and the investigated thermal bridge. These distances depend on the particular detail investigated. Generally speaking, a distance of 1 meter from the thermal bridge is required, but for example, when a symmetry plane is present at a closer distance, this symmetry plane is used as the cut-off plane. In case of the presence of ground, a larger zone around the thermal bridge in the ground is modelled. Another aspect related to the geometry of the model concerns the simplifications that are allowed. These simplifications mainly concern thin layers, the use of quasi homogeneous layers that incorporate minor thermal bridges, and changes related to the external or internal surface positions or interfaces.

Another set of rules concerns the conditions that should be applied at the boundaries of the model and the thermal conductivities or thermal resistances that should be used. The thermal conductivity of the building materials should be determined according to the standard EN ISO 10456 *[2]* or national conventions. For air layers and cavities, the thermal resistances can be determined according to different standards (EN ISO 6946 *[3]*, EN 673 *[4]* and EN ISO 10077-2 *[5]*), depending on the particular building element modelled. The boundary conditions consist of the temperatures and the surface resistances, or the heat fluxes. Temperatures can generally be freely chosen (but should be realistic in relation to radiative heat transfer), whereas surface resistances depend on the direction of the heat flux and on the purpose of the thermal bridge calculation. For surface resistances for the calculation of the linear thermal transmittance, reference is made to the EN ISO 6946 *[3]*, but simplification rules are given in addition. It should be noted that for the evaluation of the risk of superficial condensation, specific surface resistances are to be used, which are given in the standard EN ISO 13788 *[6]*.

While many other rules are described in the standard EN ISO 10211 *[1]*, it is beyond the scope of this paper to mention all of them.

Test cases for software validation

Annex A of EN ISO 10211:2007 *[1] defines* four different test cases for the validation of software. Two of them are two-dimensional (2D) models; the other two are three-dimensional (3D) models.

In order for software to be classified as a 2D steady-state high precision method, it should be able to calculate test cases 1 and 2 (2D test cases) and to fulfil the requirements associated with these.

In order for software to be classified as a 3D steady-state high precision method, it should be able to calculate all four test cases (2D and 3D test cases) and to fulfil the requirements associated with these.

Unfortunately, a couple of small but annoying errors with respect to the sign conventions have slipped into case 3[i] and case 4[ii] of Annex A of EN ISO 10211:2007 (see footnotes at the end of this paper for details). Even though the corrections are self-evident, so as to avoid any further confusion and officially remove any doubts, it seems warranted to publish a corrigendum in the short term (which should also include the correction of other small mistakes elsewhere in the text).

This practical example is illustrative of easily avoidable errors, which regrettably occur more often in definitive versions of standards. Generally speaking, the authors themselves make great efforts and sacrifices, often in difficult working conditions, so as to deliver texts as good as reasonably achievable. In order to reduce the occurrence of such type of evident errors in future standards/revisions, structural improvements in the standardisation process seem therefore called for. These may include such things as the structural and systematic provision of sufficient means and financing allowing for the development of professional, high quality standards, and the institution of systematic final quality checking procedures (e.g. by remunerated third persons, not previously involved in the drafting process).

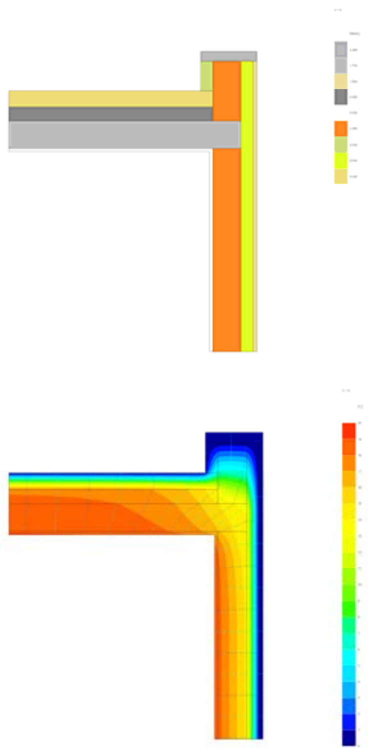
In the framework of EPB-regulations, it seems highly desirable that all MS explicitly require that software used for thermal bridge calculations fulfils at least these test cases. From the survey, it appears that this is actually already the case in the Czech Republic and in Spain, and it is planned in Belgium.

While the validation according to the EN ISO 10211 *[1]* gives a first indication of the quality of the calculation software, it appears that these test cases are not sufficient to ensure that the software will correctly calculate all situations encountered. Indeed, the four test cases are all based on rectangular geometries, so that errors or imprecisions related to non-rectangular situations are not addressed. Nor do the test cases cover any kind of air layers, losses through the ground or more complex boundary conditions.

Often, software capable of doing thermal bridge calculations can also calculate heat transfer through window frames. For this type of calculation, a set of ten test cases is given in Annex D of the European/International standard EN ISO 10077-2:2003 *[5]*. The successful validation of software according to this standard widens the scope of applicability of the software and increases the degree of confidence about the general quality of the software.

Other European/International transmission standards

EN ISO 10211:2007 *[1]* is part of a larger suite of standards that together should deal with all the aspects of thermal transmission calculations. It concerns among others EN ISO 13789 *[7]*, EN ISO 6946 *[3]*, EN ISO 13370 *[8]* and EN ISO 10077-1 *[9]* and -2 *[5]*. However, when systematically and rigorously applying the standards, a number of issues remain unanswered, or it is unclear how the recent changes in another standard affect thermal bridge calculations. This is for instance the case for slightly ventilated air layers. Different readers have different interpretations for the application to thermal bridges. Additional specifications or examples in the standard could clarify such issues.



Example of a model and the associated results from a numerical calculation.

Although in past revisions great strides have already been made to better adjust the different transmission standards among each other, some voids and inconsistencies still remain. Therefore, in order to achieve a fully streamlined set of transmission calculation rules, it appears desirable that at the time of the next revision of these standards, they are merged into one single standard, with unified definitions, terminology and symbols. This may better guarantee that the total coherence among all different aspects is fully thought through in the published text. The present standards of the transmission suite could then form the basis for different parts of such a fully adjusted, unique standard.

3 > Software tools

Over the past 2-3 decades, dedicated software for the numerical calculation of thermal bridges has been developed, in pace with the astounding advance of computer technology. From experimental research tools for specialists on basic computing machines in the early days, these tools have become ever more powerful and user-friendly, lowering the threshold for more generalised use. Their present features are already impressive, and there is no reason to assume this evolution will cease.

The table below gives an overview of a selection of current software, with the characteristics and abbreviations as explained below. All the software is available in an English language version, except when otherwise indicated.

Name	Type	2D/3D	SS/TR	FF/RECT	ψ-value	License	Validation
Heat transfer software							
AnTherm [36]	H-T (1)	3D	SS	R	Y	commercial	EN ISO 10211:2007 EN ISO 10077-2:2003
Argos (2) [37]	H-T	2D	SS	FF	Y	commercial	
Bisco / Bistra [38] / [39]	H-T	2D	SS / TR	FF	Y	commercial	EN ISO 10211:2007 EN ISO 10077-2:2003
Champs-bes [40]	HAM-T	2D	TR	R		free	EN ISO 10211:2007
David32 [41]	H-T	3D	SS	R		free	EN ISO 10211:2007
Delphin [42]	HAM-T	2D	TR	R		commercial	EN ISO 10211:2007 HAMSTAD Benchmarks 1 to 5 EN 15026:2007
Flixo [43]	H-T	2D	SS	FF	Y	commercial	EN ISO 10211:2007 EN ISO 10077-2:2003
FramePlus [44]	H-T					commercial	
HAMLab [45]	HAM-T	3D	TR	FF		free	(3)
Heat2 [46]	H-T	2D	TR	R	Y	commercial	EN ISO 10211:2007 EN ISO 10077-2:2003
Heat3 [47]	H-T	3D	TR	R	Y	commercial	EN ISO 10211:2007
KOBRA v3.0w (4) [48]	H-T	3D	SS	R	Y	free (5)	EN ISO 10211:2007
KOBRU86 / Sectra [49] / [50]	H-T	2D	SS / TR	R	Y	commercial	EN ISO 10211:2007
RadTherm [51]	H-T	3D	TR	FF		commercial	
Solido [52]	H-T	3D	SS	FF		commercial	EN ISO 10211:2007
TAS ambiens [53]	H-T	2D	TR	FF		commercial	EN ISO 10211:2007
Therm [54]	H-T	2D	SS	FF		free	EN ISO 10211:2007 (6)
Trisco / Voltra [55] / [56]	H-T	3D	SS / TR	R	Y	commercial	EN ISO 10211:2007
UNorm [57]	H-T	3D	SS	R	Y	free	EN ISO 10211:2007 EN ISO 10077-2:2003
WUFI 2D 3.2 [58]	HAM-T	2D	TR	FF		commercial	EN ISO 10211:2007
General purpose software							
Ansys multiphysics [59]	M-Phys	3D	TR	FF		commercial	
Ansys CFX [60]	M-Phys	3D	TR	FF		commercial	
Fluent [61]	M-Phys	3D	TR	FF		commercial	
Phoenics [62]	M-Phys	3D	TR	FF		commercial	
Comsol multiphysics [63]	M-Phys	3D	TR	FF		commercial	EN ISO 10211:2007
SAMCEF thermal [64]	H-T	3D	TR	FF		commercial	

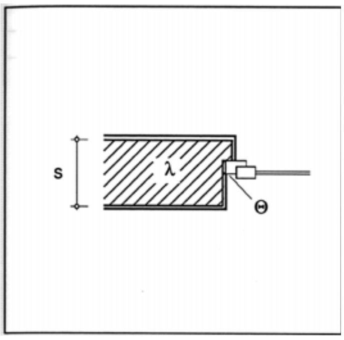
(1) Vapour diffusion can also be calculated
(2) Only available in German
(3) Not directly validated, but uses Comsol multiphysics as calculation core
(4) Only available in Dutch and French
(5) At present only for construction projects on Belgian territory
(6) Not yet validated by the developer itself, but the validation files are available on the website of the Flemish Passive House Platform [65]

- Capabilities of the software : Heat Tranfer only / Heat, Air and Moisture transfer / general, MultiPhysics (H-T, HAM-T or M-Phys): The physical models included in software can vary. Some of them are able to model heat and moisture transfer through building components, while others are limited to heat transfer or can model a wide range of physical phenomena (fluid flow, heat conduction, radiative heat transfer, etc.).
- 2D/3D: Some software has only the capability of calculating 2D models. Note that usually, 3D software can also be used to calculate 2D models.
- Steady-state or transient (SS or TR): Some software can only calculate equilibrium temperatures and heat fluxes in a model (steady-state simulations). While transient simulations are usually not required for thermal bridge calculations within the framework of EPB-regulations, they can be useful for example for calculations of heat losses through the ground with periodic variation of external conditions (see § 10.5 of EN ISO 10211 *[1]*). Note that software capable of calculating transient cases can usually also calculate steady-state solutions.

- Free-form/rectangular model (FF or R): Some software is limited to rectangular models while others can calculate free-form models.
- Automatic calculation of the linear thermal transmittance (ψ - value: Y): In some software, the linear thermal transmittance according to EN ISO 10211 is calculated automatically.
- Free/commercial: Some software is distributed free of charge, other under an open source license, and still other is commercially licensed.
- Validations: The last column mentions which validation test cases are made available on the supplier company's website as program input files (possibly in combination with a written report that discusses the calculation results). By downloading the test files, the user of a given program can readily verify by himself/herself whether that program satisfies the criteria defined in the standards. **Note that in the framework of the ASIEPI project NO independent check has been performed of the test cases of the different programs.** The claims on the websites of the companies remain the sole responsibility of these companies. But on the other hand, not a single report has been received at present that any of the test files would not comply with the validation criteria.

4 > Thermal bridge atlases

While the evaluation of linear thermal transmittance can be done using software as explained above, for standard details it may be easier and faster to make use of an atlas of thermal bridge details. The main advantage of using such atlases is that no calculations are needed, so the information can be obtained rapidly and with less preliminary knowledge. The main disadvantages are that the number of details necessary to cover the many situations encountered in reality is quite large, and the flexibility is usually lower. Moreover, when using an atlas, one must make sure that the conventions used for obtaining the values of the atlas are in accordance with the conventions set by the national EPB-regulations. Atlases that aren't general enough may therefore not be applicable in all countries. This is less of a problem with software though, as it is more flexible.



s [cm]	λ = 0,21		λ = 0,56		λ = 0,99	
	WBV	Θ	WBV	Θ	WBV	Θ
24	0,04	0,75	0,07	0,69	0,11	0,62
30	0,05	0,74	0,10	0,67	0,14	0,60
36,5	0,07	0,73	0,12	0,66	0,18	0,60

Example of data given in a thermal bridge atlas (taken from [18]).

There are different kinds of thermal bridge atlases. Many exist as stand-alone documents, originally developed independently of the EPB-regulation. But in some Member States, thermal bridge atlases have been developed specifically for the EPB-regulation. Such atlases can be of the ordinary type, i.e. a simple collection of building details with corresponding values of interest (e.g. linear thermal transmittance, temperature factor, ...). Or it can be a set of details that are considered as good-practice details in the framework of the EPB-regulations. The latter approach is an important evolution in the way of dealing with thermal bridges. This change started about a decade ago. Focus has been shifting from ever more systematic and detailed analysis of thermal bridges to their avoidance as much as reasonably possible. A detailed quantification of thermal bridges is then usually considered as no longer necessary, and the designer is dispensed with this time-consuming task, a task that by itself does not solve the thermal bridge. This important new development will be presented in a future ASIEPI Information Paper.

Finally, values of linear thermal transmittances are also given in the European/International standard EN ISO 14683 *[10]*. But the number of details in this standard is small, they are rather simplistic, and the values are on the safe side, which makes it quite difficult to use it in practice to obtain precise evaluations of the thermal bridges.

The table below summarizes the main atlases that are used in the surveyed countries. A special case of an atlas is the highly flexible electronic atlas

Flexibility of an atlas is to be understood as follows:

Y: a number of variations of parameters (dimensions, thermal conductivities,…) is taken into account for each detail

N: no variations of the parameters

"KOBRA", initially developed as a DOS programme in the framework of the European project "Eurokobra" and more recently made compatible with the Windows operating system. In this atlas, the dimensions, the thermal conductivities and the boundary conditions of predefined topologies can be changed and the value of the linear thermal transmittance is accurately recalculated for the precise case. It is thus in effect a combination of an atlas and a numerical calculation programme, but it requires no specific modelling knowledge of the user.
While in most of the surveyed countries thermal bridges atlases are reported in common circulation, they don't appear to be widely used in Greece, Italy, the Netherlands and Finland.

Name	Language	Number of details	Types of buildings	Flexibility	Integral Part of EP-reg	In use in MS...
EN ISO 14683 : Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values (ISO 14683:2007) [10]	English	76	Residential	N	N	Europe
KOBRA v3.0w [11]	French and Dutch	3000+	All types	Y	N	Belgium
Construction details – Thermal Bridges [12]	Czech	56	All types	Y	N	Czech Republic
U-values 2003 [13]	Danish	2000+	All types	N	N	Denmark
Danish Standard 418. Calculation of heat loss from buildings [14]	Danish	275+	All types	N	Y	Denmark
2005 thermal regulation, Th-U 5/5 Thermal bridges for new building [15]	French	10000+	New building	Y	Y	France
Th-U 5/5 Thermal bridges for existing building [16]	French	3000+	Existing building	Y	Y	France
Thermal bridge atlas for wooden constructions [17]	German	3000+	Wooden constructions wall, ceiling, roof	Y	N	Germany
Thermal bridge atlas for brick constructions [18]	German	8000+	Brick constructions with/without insulation, ceiling, roof	Y	N	Germany
Building Research Design Sheet 471.017, Thermal bridges - Tables with ψ values [19]	Norwegian	23	All types	Y	N	Norway
Electronic atlas of thermal bridges ("Kuldebroatlas") [20]	Norwegian	23+	All types	Y	N	Norway
Thermal bridges - Calculation, ψ values, and influence on energy consumption. Project report 25-2008 [21]	Norwegian	31	All types	Y	N	Norway
Thermal Bridges Catalogue Traditional Buildings [22]	Polish	100+		N	N	Poland
Thermal bridges. Basics, simple formulaes, heat loss, condensation, 100 calculated building details. [23]	German	100	All types	N	N	Austria
Thermal Bridges in Constructive Elements Catalog for Building Technical Code [24]	Spanish	300+	All types	Y	Y	Spain
Building regulation STR 2.05.01:2005 "Thermal technique of the building envelope", Annex 7 [25]	Lithuanian	200	All types	Y	Y	Lithuania
Thermal bridges catalog [26]	German	200+	All types	Y	N	Switzerland
Code for thermal energy performance calculation of building's elements C107/3-2005 [27]	Romanian	1500+	All types	N	Y	Romania
Limiting Thermal Bridging and Air Infiltration Acceptable Construction Details [28]	English	150	All types	Y	Y	Ireland
Accredited construction details [29]	English	150	Dwellings	N	Y	United Kingdom
Accredited construction details (Scotland) [30]	English	130	Dwellings	N	Y	United Kingdom
Enhanced Construction Details [31]	English	47	Dwellings	N	N	United Kingdom
Thermal bridge catalog [32]	German	323	All types	Y	N	Germany
BuildDesk (1) [33]	Polish	100+	All types	N	N	Poland
CERTO (1) [34]	Polish	100+	Traditional and concrete panel	N	N	Poland
Thermal bridge catalogue for renovation and retrofit measures to prevent mould [35]	German	92	All types, renovation	Y	N	Germany

(1) Certification software that also contains a thermal bridge atlas

5 > Conclusions and recommendations

From the survey summarised in this paper, it can be seen that many tools exist for the evaluation of thermal bridges.

Concerning the software, the main problem encountered at the start of the enquiry was the lack of systematic and up-to-date proof of validation. At the time of publication of this paper, some software still did not have documented validation. There lingers a certain degree of doubt over the calculation results of such non-validated software. Their use in the framework of EPB-regulations of MS should therefore better be avoided.

Concerning the thermal bridge atlases, it appears that a whole collection of such documents is available. Most of them are written in the language of their original country and are not translated. Of course, this may be one of the main reasons that render the use of such documents difficult in other countries.

Overall, the following practical recommendations can be formulated to the different main actors:

- Member States:
    - They can be advised to explicitly require that software used in the context of their EPB-regulation at least satisfies the validation cases of the most recent version of EN ISO 10211. At present this is the publication of 2007.
- CEN/ISO:
    - It seems highly desirable to publish in the short term a corrigendum for the errors in cases 3 and 4 of annex A (and elsewhere in the text) of EN ISO 10211:2007.
    - In order to avoid repetition of such type of errors in future standards/revisions, structural improvements and systematic quality checks in the process of establishing standards might be indicated. This may require additional funding.
    - In a future revision of the EN ISO 10211, a more comprehensive set of validation test cases seems warranted, e.g. also encompassing more complex boundary conditions, non-rectangular geometries and air layers.
    - Further improvement, streamlining and clarification of the EN ISO transmission standards appear desirable: this can probably best be achieved by merging all present standards from the transmission suite into (different parts of) one single, fully coherent standard, with unified definitions, terminology and symbols.
- Software developers:
    - Validate systematically and continuously all thermal bridge software according to the latest versions of European and International standards and other benchmarking methods, and publish any proof of validation (including calculation files) on the internet.
    - Continue the further improvement of the capabilities and user friendliness of thermal bridge software.
- Translation of the available atlases in English, in order to allow a wider use. This may in particular be relevant for the new generation of atlases with solutions to avoid/minimise thermal bridges. In this way the Member States can profit from the efforts of each other and of common European developments. The topic of such solution-oriented atlases will be discussed in more detail in a future Information Paper.

6 > References

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[i] Practically speaking, it concerns the following points:

- figure A.3.b: the boundary condition between A and C should be γ
- equation A.5 should read: $\Phi_{\beta,\alpha}$ = ...= 2,094 x (15-20) = -10,47 W
- equation A.7 should read: $\Phi_{\beta,\gamma} + \Phi_{\alpha,\gamma}$ = 24,36 + 35,62 = 59,98 W
- equation A.8 should read: $\Phi_{\beta,\gamma} + \Phi_{\beta,\alpha}$ = 24,36 - 10,47 = 13,89 W
- equation A.9 should read: $\Phi_{\alpha,\gamma} + \Phi_{\alpha,\beta}$ = 35,62 + 10,47 = 46,09 W

[ii] Second paragraph of the section A.1.5 Case 4 : "lowest internal surface temperatures" should be replaced by "highest surface temperature on the external side"

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