INTERNATIONAL SCIENTIFIC CONFERENCE

CIBv 2010

12 – 13 November 2010, Braşov

THE USE OF THE THERMAL COUPLING COEFFICIENT IN ESTABLISHING THE THERMAL PERFORMANCE OF AN APARTMENT

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Abstract: Similar to the mechanical behavior of the resistance structure of a building which is completely characterized by the stiffness matrix of the structure, the thermal performance of a building is fully characterized by the thermal coupling coefficients matrix of the functions in a building and air exchanges matrix between the functions in the building. Determination of thermal coupling matrix is made in accordance with EN ISO 10211:2007 standard, based on spatial temperature field in thermal stationary regime, inferred for a spatial network that includes the building and the ground on which the building is placed [1]. The vertical planes that are sectioning the land around the building are considered at a distance of 2.5 x width of the building on all sides, and in the soil to a depth of 7 m. The paper will present a method for the calculus of the energy performance of buildings that uses the above mentioned matrixes.

Key words: mathematical modelling, simulation, heat transfer, dynamic modelling, building energy performance.

1. INTRODUCTION

The paper presents numerical results obtained for a block of flats situated in Cluj Napoca town (IIIrd climatic zone Θ_e=-18^{o}C), having a prefabricated structure and a GF+ 4F system of height. The study was made on 3 variants of thicknesses for the thermal insulation layer placed on the exterior face of the exterior walls (10 cm, 12 cm and 15 cm expanded polysterene). Only the results obtained for the maximum thickness will be presented.

The building has 2 staircases and a basement level below the entire building. Each level has 2 apartments, with 3 rooms at ground floor and at the last level, 3 and 4 rooms at levels 1, 2 and 3, kitchen, bathroom, toilet service and vestibule. Apartments at upper levels are provided with balconies. The building has interior walls of 14 cm thickness of reinforced concrete and exterior walls made of big prefabricated panel of 27 cm thick. The prefabricated closing panel of the building has a constructive solution formed of three layers, with a thermal protective layer of 12.5 cm thick made of ACC. The height level of the building of 2.70 m is constant, the terrace is thermally insulated with expanded slag with an average thickness of 30 cm. The building has an east-west orientation with the main facade south orientated.

2. PRESENTATION OF THE CALCULUS PROGRAM

2.1 Generalities

The thermal coupling coefficients matrix is established for each function of the building (apartment, staircase, basement), and in an apartment for each functional area of the apartment, whether or not there exists heating bodies. This matrix includes terms that capture the heat exchanges with the exterior, the heat exchanges between the functional areas of the building, the heat exchanges between the functional areas of an apartment and the heat exchanges between the functional areas of the apartment with the functional spaces of the adjacent apartments.

The air exchanges matrix is determined for exchanges between the functional areas of the apartment and the exterior, between the functional areas of the apartment, between the flat and the staircase, between the staircase and the exterior of the building, between the staircase and the basement, and between the spaces of the basement and the exterior of the building and between the basement and the staircase.

Based on energy balance equations written simultaneously on the entire building, the energy balance is written for each function of the building based on the thermal coupling coefficients matrix and the air heat exchanges matrix, and the air temperatures of the spaces that have no heating bodies are determined.

Knowing the equilibrium temperatures of the air in each function of the building and of the apartment by using the coefficients values of the two matrices, the heat losses through heat transfer and heat losses by ventilation can be determine. Based on the heat necessary for heating and ventilating a building, depending on the efficiency of the heating system (generation, transmission and distribution, static bodies), the energy necessary for heating and ventilation of the building will be determined.

The calculus method allows in the cold period of the year to take into account the effect of the use of a ventilation system with heat recovery. The method also enables the determination of the cold demand for cooling the apartments in the warm period of the year.

2.2 Program descriptions

The thermal energetic analysis of the building or of the apartments is made based on a spatial temperature field in thermal stationary regime, obtained in the nodes of a spatial discretization network of the building and of the ground on which the building is located. The discretization, the writing of equations and the solving of the resulted spatial system of equations is given by the calculus program “CIMPSPAT” 2010 version (first version dating from 1981).

The program is based on the mathematical modelling for the heat transfer in spatial thermal stationary regime such as:

$$\frac{\partial}{\partial x}\left[\lambda(x,y,z)\cdot\frac{\partial T(x,y,z)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda(x,y,z)\cdot\frac{\partial T(x,y,z)}{\partial y}\right]+\frac{\partial}{\partial z}\left[\lambda(x,y,z)\cdot\frac{\partial T(x,y,z)}{\partial z}\right]=0 \qquad (1)$$

In solving the above equation the numerical high accuracy calculus method of the heat balance equilibrium in each node of the spatial discretization network, provided in the EN ISO 10211:2007 standard, Annex A, was used [1] It met The criteria for validation foreseen in Annex A were accomplished. The meshing of the spatial geometrical model is performed automatically by the computer calculus program, resulting in a spatial meshing network with steps between 5 and 20 mm in all directions. The error estimator generates the need to extend the degree of subdivision of the calculus network. This is done automatically by the calculus program until the condition that between the flow of the inner and outer surfaces of the wall exists a difference under 0.001W, is satisfied. In each node of the spatial calculus network differences under 0.000001 W must be obtained, superior condition to the one specified in EN ISO 10211:2007, pointA.2.e.[1]

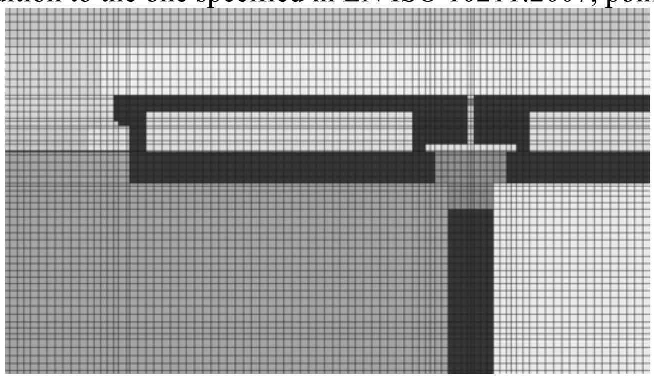


Fig. 1 Discretization network

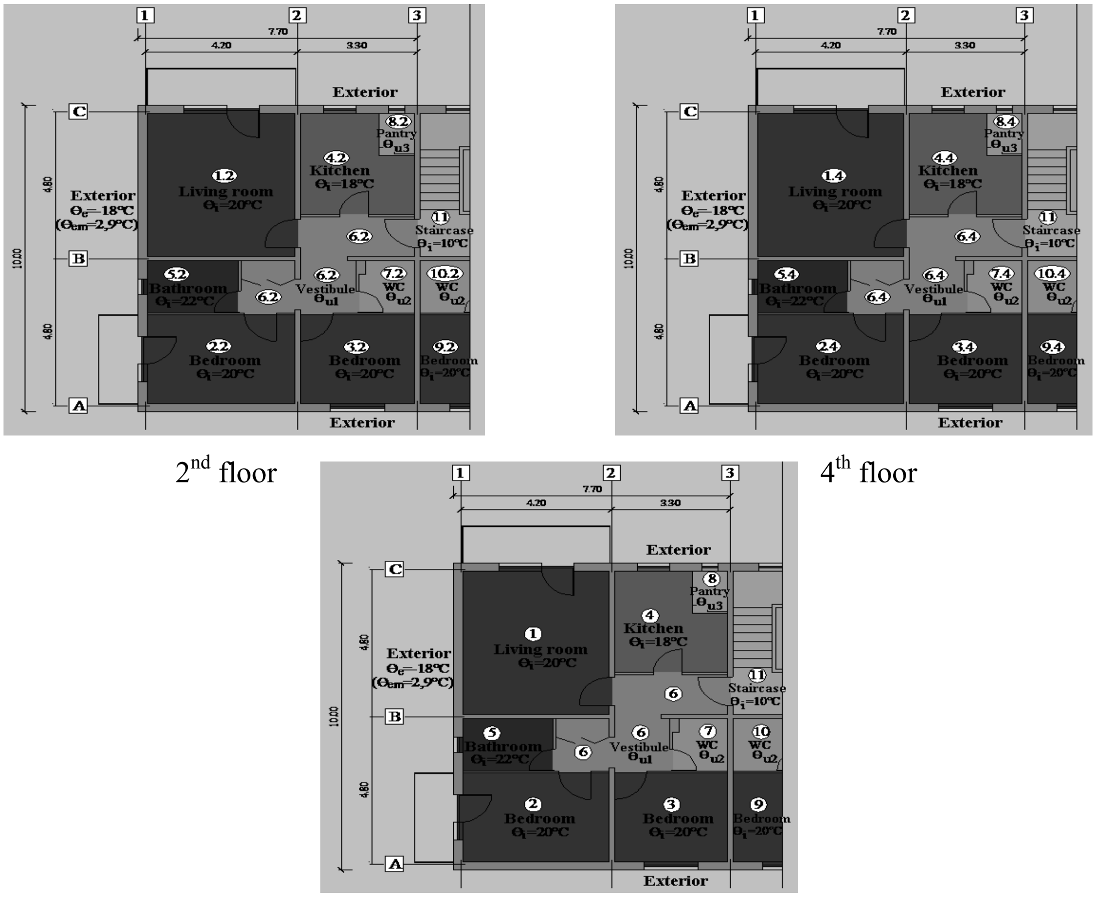
The programming language used for the calculus program has developed from Fortran to Pascal and up to Delphi 7, having inserted the calculus modules in C++ language. The number of the material types that can be used in the program for describing the geometrical model and the number for the contour conditions is unlimited. The program library contains catalogues with the necessary elements for defining the building envelope, arranged by constructive and dimensional types. Also the program contains a library with climatic data in accordance with the SR EN ISO 13790 standard and other specific standards, the exterior air temperature, direct and diffuse solar radiation by orientations, and for Cluj the speed and dominant winds direction, the humidity of the exterior air and the atmospheric pressure [2]. Spatial geometry of the building and detailed geometry of the building elements is introduced as input data using a graphics processor, designed in this sense. Based on those, the geometric features of the building are determined (perimeter, useful area, usable volume, built area). This calculation program is similar to any other calculation program that use spatial fields of temperature, the results being identical because of the energetic balance equations systems that are written in the network nodes and whose mathematical solutions are unique regardless of the type of calculation program. The software was validated in accordance to all 4 cases of ISO 10211:2007, Annex A, for three-dimensional calculation programs, similar to other known software.[1]

3. **CASE STUDY**

Due to limited space for the paper, from the three variants of thicknesses for the expanded polystyrene layer, the results obtained for the case of 15 cm of insulation and for the case of thermally uninsulated building, will be presented.

Given the current concern in Romania on individual energy certification of apartments of a building, detailed results obtained for an apartment placed at the edge of the building located on the 3rd floor, will be presented

Due to the large number of results obtained for the entire building, physically they can not be presented in the given space.



2nd floor

4th floor

3rd floor

Fig. 2 The numbering and the temperatures in the rooms

3.1 Obtained results and analysis results

In table (1) and (2) are presented the thermal coupling coefficients obtained for the functions of the studied apartment, both with the exterior and with the functions of the upper and lower apartment, and with the staircase. The thermal coupling coefficients calculus and presentation was made in accordance with point c.2 of Annex C, of EN ISO 10211:2007 standard.[1]

In tabel 1 are presented the thermal coupling coefficients obtained for the uninsulated building and in tabel 2 for the building thermally insulated with 15 cm of expanded polystyrene. In tabel 4 are presented the specific annual energy consumption indexes [kWH/(m$^{2\cdot}$year)] for each function of the apartment and total on the apartment, and the energy classification under the energy classification scale for heating buildings during the cold season, currently valid in Romania.

Results are presented for heating installations with a system efficiency of 75%, 80%, 85% and 90%, and for each efficiency case was considered a degree of heat recovery from the ventilated air of 0%, 25%, 50% and 75%. Presentation of results for each function of an apartment allows proper sizing of the heating bodies individually for each function.

Table 1 Thermal coupling coefficient –the thermally uninsulated building

The functions of the building	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exterior	32.45	25.85	12.10	8.11	6.23	-	-	3.83
(1)	-	-	-	26.26	19.99	21.54	-	-
(2)	-	-	22.47	-	23.78	12.26	-	-
(3)	-	22.47	-	-	-	12.78	14.89	-

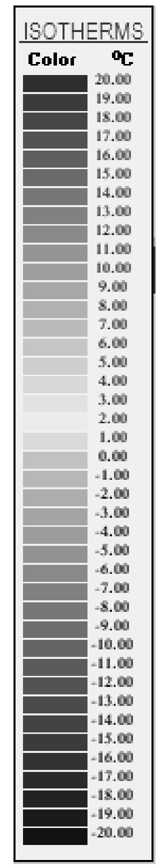
(4)	26.26	-	-	-	-	27.29	-	18.12
(5)	19.99	23.78	-	-	-	13.90	-	-
(6)	21.54	12.29	12.78	27.29	13.90	-	26.35	-
(7)	-	-	14.89	-	-	26.35	-	-
(8)	-	-	-	18.12	-	-	-	-
(9)	-	-	22.48	-	-	-	0.78	-
(10)	-	-	0.78	-	-	0.81	12.96	-
(11)	-	-	-	16.72	-	9.64	0.88	11.51
(1.2)	52.51	-	-	1.03	0.79	0.84	-	-
(2.2)	-	32.31	0.88	-	0.74	0.46	-	-
(3.2)	-	0.88	25.04	-	-	0.47	0.46	-
(4.2)	1.04	-	-	24.31	-	0.89	-	0.63
(5.2)	0.79	0.74	-	-	11.34	0.46	-	-
(6.2)	0.94	0.46	0.47	0.89	0.46	26.25	0.95	-
(7.2)	-	-	0.46	-	-	0.95	6.87	-
(8.2)	-	-	-	0.63	-	-	-	3.39
(9.2)	-	-	0.88	-	-	-	0.04	-
(10.2)	-	-	0.04	-	-	0.04	0.49	-
(1.4)	52.46	-	-	1.03	0.79	0.94	-	-
(2.4)	-	32.26	0.87	-	0.73	0.46	-	-
(3.4)	-	0.87	25.05	-	-	0.47	0.46	-
(4.4)	1.03	-	-	24.27	-	0.89	-	0.63
(5.4)	0.79	0.73	-	-	11.32	0.46	-	-
(6.4)	0.83	0.45	0.47	0.89	0.45	26.18	0.94	-
(7.4)	-	-	0.45	-	-	0.94	6.86	-
(8.4)	-	-	-	0.62	-	-	-	3.38
(9.4)	-	-	0.87	-	-	-	0.04	-
(10.4)	-	-	0.040	-	-	0.04	0.49	-

Table 2 Thermal coupling coefficients- the thermally insulated building with 15 cm of expanded polystyrene

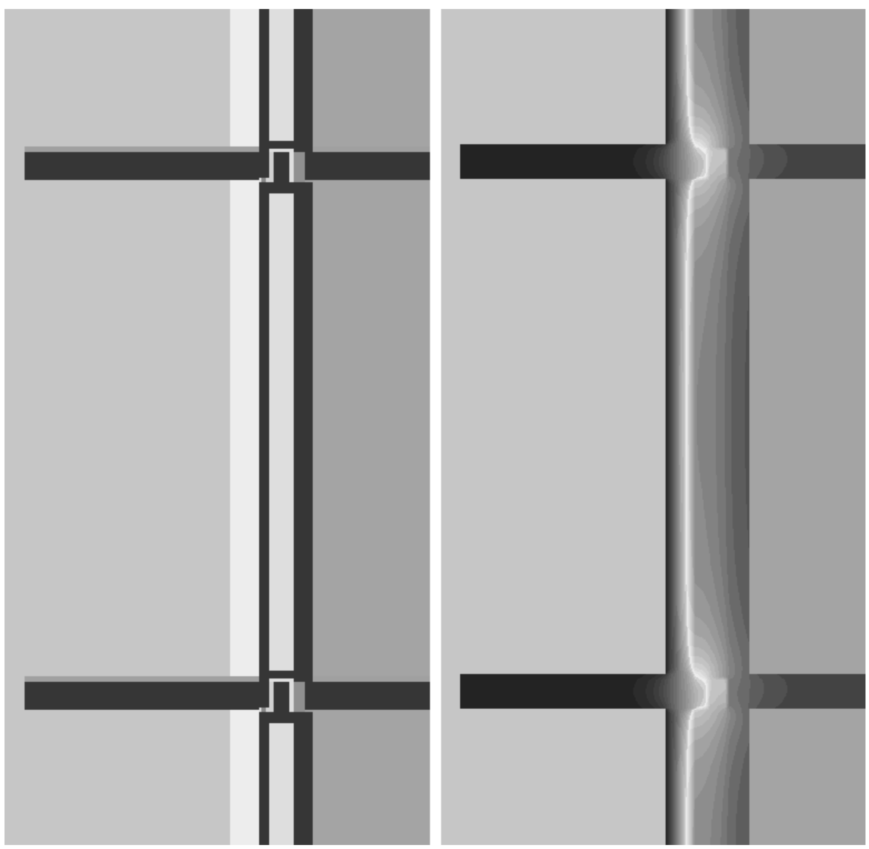
The functions of the building	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exterior	11.36	8.91	4.49	2.92	1.66	-	-	0.98
(1)	-	-	-	26.59	20.34	21.54	-	-
(2)	-	-	22.82	-	24.09	12.29	-	-
(3)	-	22.82	-	-	-	12.75	14.89	-
(4)	26.59	-	-	-	-	26.89	0.39	18.42
(5)	20.34	24.09	-	-	-	13.89	-	-
(6)	21.54	12.29	12.75	26.59	13.8	-	27.49	-
(7)	-	-	14.89	0.39	-	27.49	-	-
(8)	-	-	-	18.42	-	-	-	-
(9)	-	-	22.83	-	-	-	0.78	-
(10)	-	-	0.78	-	-	0.75	13.02	-
(11)	-	-	-	16.72	-	4.44	6.08	11.89
(1.2)	53.59	-	-	1.05	0.81	0.84	-	-
(2.2)	-	33.17	0.90	-	0.76	0.46	-	-
(3.2)	-	0.90	25.45	-	-	0.47	0.46	-
(4.2)	1.06	-	-	24.57	-	0.88	0.02	0.65
(5.2)	0.81	0.76	-	-	11.54	0.46	-	-
(6.2)	0.94	0.46	0.47	0.89	0.46	25.97	1.21	-
(7.2)	-	-	0.46	-	-	0.94	6.87	-
(8.2)	-	-	-	0.66	-	-	-	3.51
(9.2)	-	-	0.90	-	-	-	0.04	-
(10.2)	-	-	0.04	-	-	0.04	0.50	-
(1.4)	53.53	-	-	1.05	0.81	0.93	-	-
(2.4)	-	33.1	0.89	-	0.75	0.45	-	-
(3.4)	-	0.89	25.38	-	-	0.47	0.46	-
(4.4)	1.05	-	-	24.53	-	0.88	-	0.65
(5.4)	0.81	0.75	-	-	11.52	0.46	-	-
(6.4)	0.83	0.45	0.47	0.89	0.45	26.16	0.95	-
(7.4)	-	-	0.45	-	-	0.94	6.86	-
(8.4)	-	-	-	0.640	-	-	-	3.49
(9.4)	-	-	0.89	-	-	-	0.04	-
(10.4)	-	-	0.04	-	-	0.04	0.49	-

Table 3 The specific annual energy consumption indexes [kWH/(m^{2}year)]- the thermally insulated building with 15 cm of expanded polystyrene

CASE STUDY					FUNCTIONS	LIVING ROOM	BEDROOM1	BEDROOM2	KITCHEN	BATHROOM	VESTIBULE	WC	PANTRY	TOTAL APARTMENT
UNINSULATED					INDEX	345.26	375.16	234.55	385.91	561.08	73.22	84.94	716.95	*313.04*
					LETTER	F	F	D	F	G	B	B	G	*E*
THERMALLY INSULATED 15 cm	Efficiency of the heating system	75%	Ventilation with heat recovery	0%	INDEX	153.34	147.75	113.13	249.52	322.22	34.38	144.67	549.07	*160.30*
					LETTER	C	C	B	E	E	A	C	G	*C*
				25%	INDEX	138.34	132.74	98.12	236.02	305.72	34.38	144.67	549.07	*148.33*
					LETTER	C	C	B	D	E	A	C	G	*C*
				50%	INDEX	123.34	117.74	83.12	222.51	289.21	34.38	144.67	549.07	*136.37*
					LETTER	C	C	B	D	E	A	C	G	*C*
				75%	INDEX	108.33	102.74	68.12	209.01	272.71	34.38	144.67	549.07	*124.40*
					LETTER	B	B	A	D	E	A	C	G	*C*
		80%	Ventilation with heat recovery	0%	INDEX	143.76	138.51	106.06	233.92	302.08	32.23	135.63	514.76	*150.28*
					LETTER	C	C	B	D	E	A	C	G	*C*
				25%	INDEX	129.69	124.45	91.99	221.26	286.61	32.23	135.63	514.76	*139.06*
					LETTER	C	C	B	D	E	A	C	G	*C*
				50%	INDEX	115.63	110.38	77.93	208.61	271.14	32.23	135.63	514.76	*127.85*
					LETTER	B	B	B	D	E	A	C	G	*C*
				75%	INDEX	101.56	96.32	63.86	195.95	255.67	32.23	135.63	514.76	*116.63*
					LETTER	B	B	A	D	E	A	C	G	*B*
		85%	Ventilation with heat recovery	0%	INDEX	135.30	130.36	99.82	220.16	284.31	30.33	127.65	484.48	*141.44*
					LETTER	C	C	B	D	E	A	C	F	*C*
				25%	INDEX	122.06	117.13	86.58	208.25	269.75	30.33	127.65	484.48	*130.88*
					LETTER	C	C	B	D	E	A	C	F	*C*
				50%	INDEX	108.83	103.89	73.34	196.34	255.19	30.33	127.65	484.48	*120.33*
					LETTER	B	B	B	D	E	A	C	F	*C*
				75%	INDEX	95.59	90.65	60.11	184.42	240.63	30.33	127.65	484.48	*120.33*
					LETTER	B	B	A	D	D	A	C	F	*B*
		90%	Ventilation with heat recovery	0%	INDEX	127.78	123.12	94.27	207.93	268.52	28.65	120.56	457.56	*133.58*
					LETTER	C	C	B	D	E	A	C	F	*C*
				25%	INDEX	115.28	110.62	81.77	196.68	254.76	28.65	120.56	457.56	*123.61*
					LETTER	B	B	B	D	E	A	C	F	*C*
				50%	INDEX	102.78	98.12	69.27	185.43	241.01	28.65	120.56	457.56	*113.64*
					LETTER	B	B	A	D	D	A	C	F	*B*
				75%	INDEX	90.28	85.62	56.77	174.18	227.26	28.65	120.56	457.56	*103.67*
					LETTER	B	B	A	D	D	A	C	F	*B*



Horizontal section through the wall



Vertical section through the wall

Fig. 3 Isothermal surface

The specific annual energy consumption indexes decrease with the increase of the heating system efficiency and with the increase of the heat recovery degree from the ventilated air. Thus, the uninsulated building having an E energy class can be brought to a B energy class.

If the heating system efficiency is just 75% and in lack of ventilation systems with heat recovery (where 0%), additional thermal insulation with 15 cm of expanded polystyrene reduces the annual specific consumption to 51%.

If a performant heating system (90%) coupled with a ventilation system with heat recovery rate of 75% is used, the initial building specific energy consumption can be reduced by 33%. The other obtained results for the intermediate cases can be seen in the table.

4. CONCLUSIONS

The calculus method can be applied for determination in a single step the heat and ventilation necessary for the entire heating period of the year, or in more stages that are added up together for each month-week-day-hour of the heating period, according to the available climatic data. Compared to current practice of determination of the thermal performance of a building that sums up the thermal performances of the components of the building envelope, this method takes into account the thermal effects arising from the contact between the elements of the building envelope. The obtained results for the energy efficiency of the building with the two methods are significantly different. Failure in taking into account the thermal coupling effects between the building envelope elements, will lead to results with significant differences if the building presents variable geometry volume.

To highlight the effect of not considering the thermal contact between the building envelope elements, the case of a prefabricated panel with dimensions 3.30*2.70 m that closes on the outside bedroom 2, is presented. By comparison the values of the thermal coupling coefficient of the room with the exterior $L^{3}_{D2,e}$ [W/K], obtained for the next calculation hypothesis, are shown:

- The panel is considered placed in the envelope of the building;

- The panel is considered cut (independent) from the envelope with adiabatic planes (in accordance with EN ISO 10211:2007).

Differences between the thermal coupling coefficient values obtained in the two asessment hypotheses of the prefabricated panel, are decreasing with the increase of the themal insulation layer. Although the presented results refer to a particular case of a wall, the obtained conclusions have a high degree of generalization.

Table 4 Thermal coupling coefficients-panel case

Case study	L^{3D}		Percentage
	In the building envelope	Aside from the building envelope	%
Uninsulated	12.104	14.690	21.4
5cm	6.112	6.851	12.1
15 cm	4.996	5.141	2.9
20 cm	4.220	4.108	2.7

This method of assessing the energy performance of buildings has been applied in the thermal rehabilitation of buildings for more than 150 buildings from Romania.

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Received November 3, 2010