CONSIDERATIONS ON THE ENERGY PERFORMANCE OF A BUILDING

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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 matrix of thermal coupling coefficients of the functions in a building and matrix of air exchanges between the functions in that 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 located. The vertical planes that are sectioning the land around the building are considered at a distance of 2.5 x width of a 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.

INTRODUCTION

The paper presents numerical results obtained for a block of flats situated in the town of Cluj Napoca (IIIrd climatic zone Θ_e=-18^{o}C), having a prefabricated structure and a system of height GF+ 4F. 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 din beton armat 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.

Figure 1 The studied building

THE CALCULUS PROGRAM

General considerations

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 exist heating bodies. This matrix includes terms that capture the heat exchange 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 functional spaces of the adjacent apartments.

The matrix of air exchanges 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 matrix of thermal coupling coefficients and the matrix of heat exchanges of air, 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 recuperator. The method also enables the determination of the cold necessary for the cooling of apartments in the warm period of the year.

Program description

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:

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

To solve this equation the numerical calculus method of high accuracy calculating the heat balance equilibrium in each node of the spatial discretization network provided in the EN ISO 10211:2007 standard, Annex A. It met the criteria for validation of the Annex. The meshing 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. 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 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.

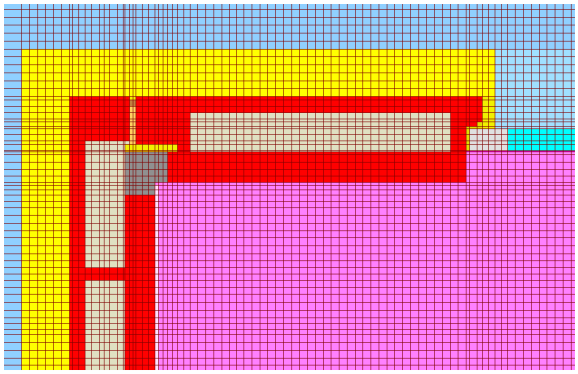


Figure 2 Discretization network

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 direction of the dominant winds, the humidity of the exterior air and the atmospheric pressure. 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 programs that uses spatial fields of temperature, the results being identical because 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 conform all 4 cases of ISO 10211:2007, Annex A, for three-dimensional calculation programs, similar to other known softwares: e.g. PHYSIBEL software, HEAT3 software, AnTherm software etc....

Other specific programs

During 30 years of work in the filed of construction and the field of physics of constructions, were elaborated and developed several packages of expert type programs specific to the field.

All programs designed at the department of building physics are in accordance with the stipulations of the EU legislation (framework of the EPBD) on the various calculations required to determine the thermal performance of buildings

As an example are presented 2 of the programs available at our department:

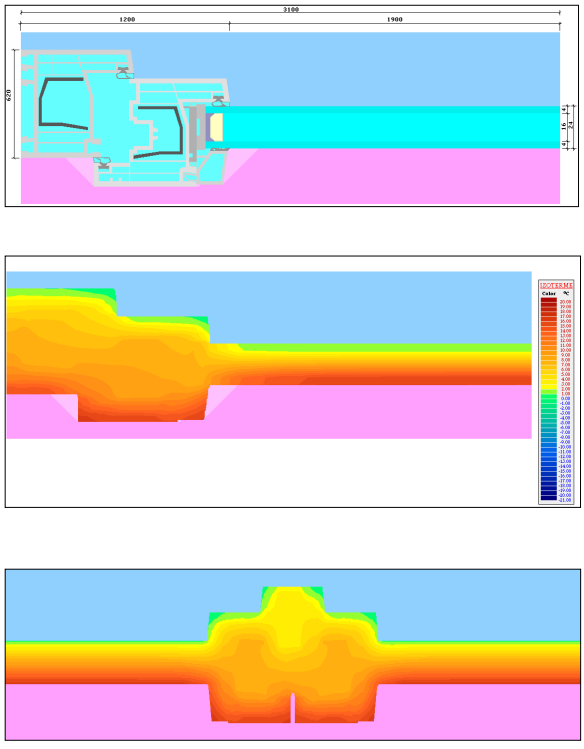


Figure 3 Program for the calculus of the thermal performance of a window- determination of ψ

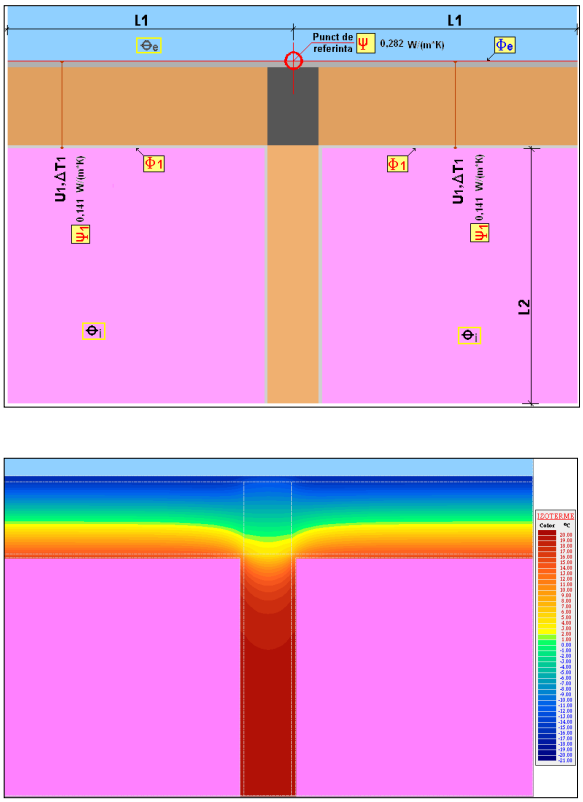
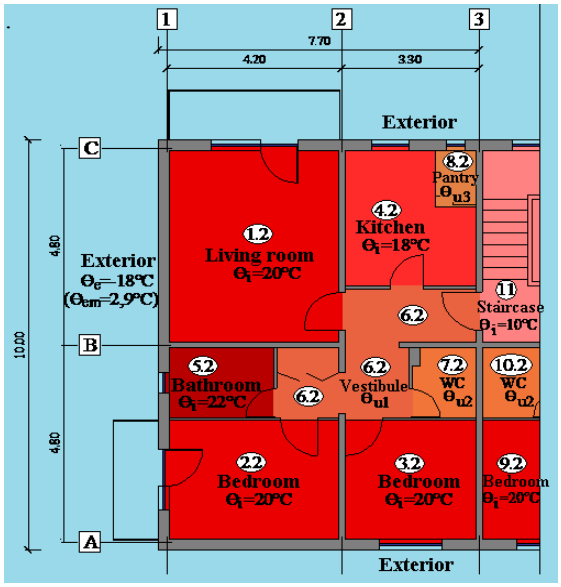


Figure 4 Program for the calculus of thermal bridges

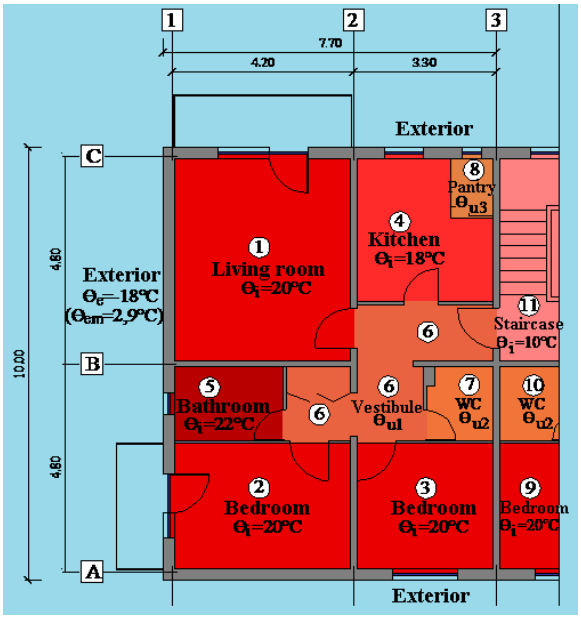
CASE STUDY

Presentation

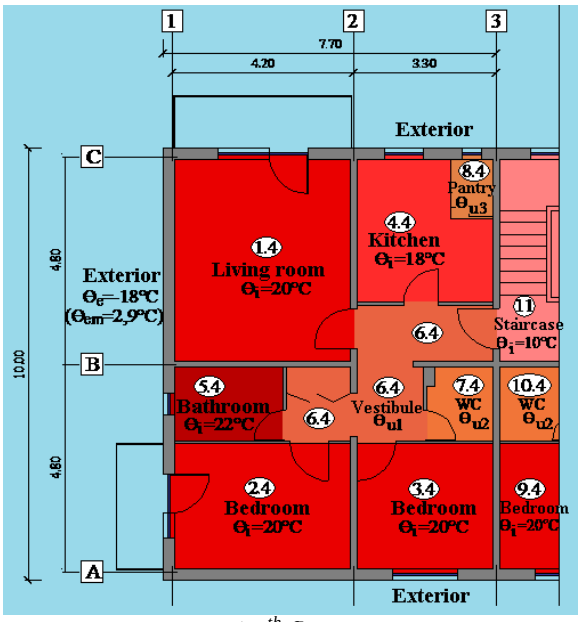
Due to limited space for the paper, from the three variants of thicknesses of the expanded polystyrene layer, the results obtained for the case of 15 cm of insulation and for the case of thermally uninsulated building will be presented.



a.) 2nd floor



b.) 3rd floor



c.) 4th floor

Figure 5 The numbering and the temperatures of/in the rooms

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

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

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.

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}an)] 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 coefficients –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	-

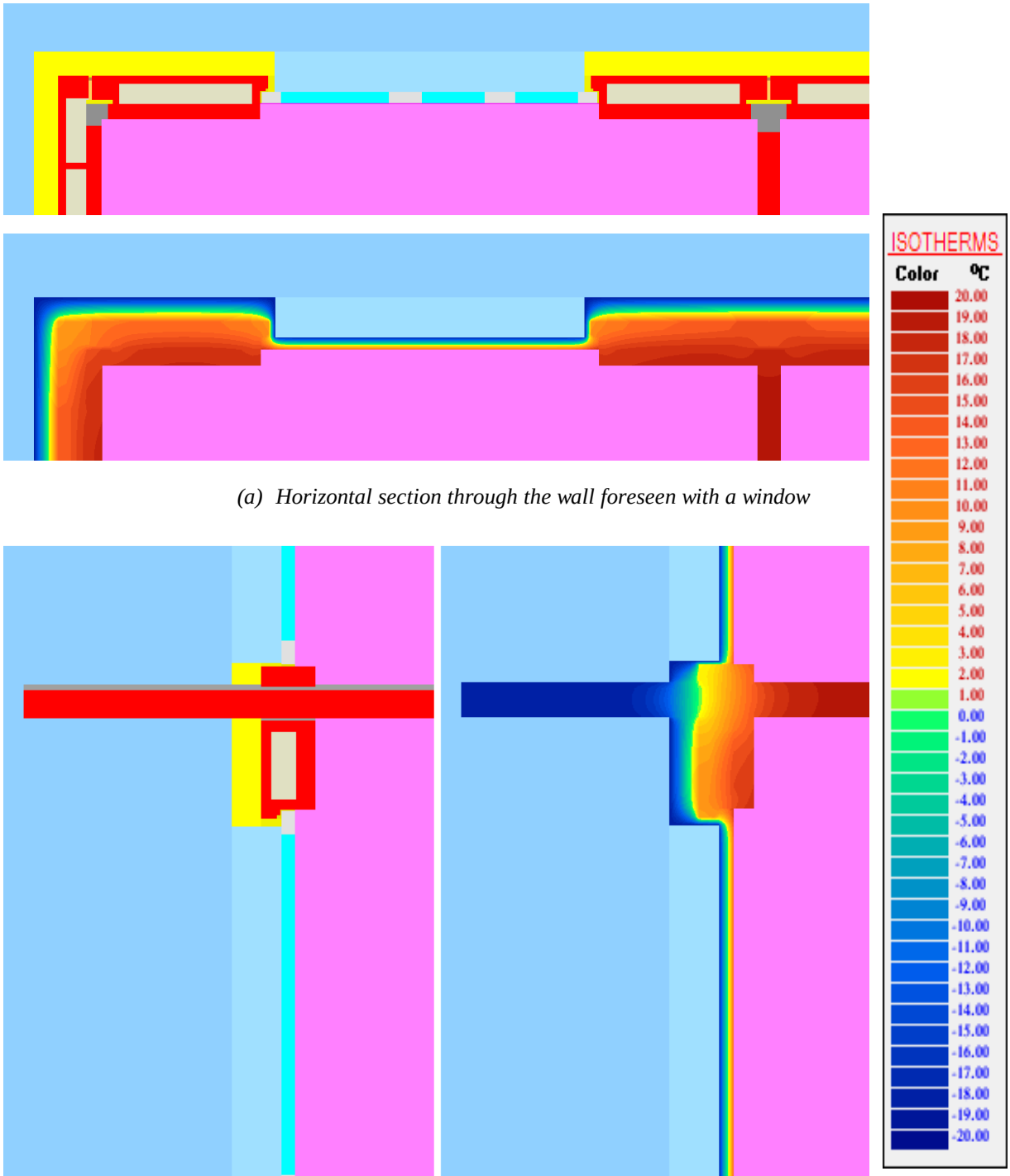
Table 2
Thermal coupling coefficients- the thermally insulated building with 15 cm of expanded polystyrene

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}an)]- the thermally insulated building with 15 cm of expanded polystyrene

CASE STUDY					FUNCTIONS	LIVING ROOM	BEDROOM 1	BEDROOM 2	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***



(a) Horizontal section through the wall foreseen with a window

(b) Vertical section through the balcony door

Figure 6 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 energetic class can be brought to a B energetic 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 resuklts for the intermediate cases can be seen in the table.

CONCLUSION

The calculus method can be applied for determination in a single step of 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 colaboration(contact) between the building envelope elements, is presented the case of a prefabricated panel with dimensions 3.30*2.70 m that closes on the outside bedroom 2. By comparison are shown 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:

- The panel is considered placed in the enevelope 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 results presented refer to a particular case of wall, the obtained conclusion have a high degree of generalization.

Table 4
The thermal coupling coefficients-panel case

Cazul de izolare termica	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
10 cm	4.996	5.141	2.9
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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