

PAPER • OPEN ACCESS

Form, Cost and Energy Efficiency for A Sing-Family House

To cite this article: Ionut Ciprian Maties *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 092049

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Form, Cost and Energy Efficiency for A Sing-Family House

Ionut Ciprian Maties ¹, Miodrag Popov ², Marius Adam ³

¹ Faculty of Architecture, 2/A, Traian Lalescu st., 300223 Timisoara Romania

² Department of Architecture, 2/A, Traian Lalescu st. 300223 Timisoara Romania

³ Department of Civil Engineering and Building Services, 2/A, Traian Lalescu st.
300223 Timisoara Romania

maties.ciprian@gmail.com

Abstract. One of the main national targets stipulated by the EPBD directive in the case of Romania is the reduction with 44% of the total energy consumption. Moreover, the residential sector has expanded significantly in the last decade, as a result of an increase in the need for housing next to the prolific urban areas. In this context, the embracement of energy efficient building concepts becomes necessary in order to reduce the energy demands of the new urban sprawls. The main purpose of the present research is to determine the comparative return of investment value for an energy efficient single-family house with a total useful area of 200 m², occupying an average plot of 600-650 m², as a common type of home suitable for a family of two adults and up to two children, in Timisoara, Romania, based on different energy consumption standards (reference level described by the national building codes, low energy and passive standard). In addition to this, from an architectural standpoint, three different volumetric approaches were considered, that comprise a constant air volume of 507-530 m³, with the aim of exploring the influence of the building form over the overall costs of the building envelope components (roof/terrace, walls and ground-floor slab). The scenarios consist of: a ground-floor flat roof house, a one-storey flat roof, as well as a one-storey with attic. The paper intends to analyse the relationship between the building form, energy performance level and cost of construction, and to search the optimum configuration of the building envelope, both in terms of form and layer composition, that allows a maximum energy efficiency level with minimum investment.

1. Introduction

One of the main goals of today's building district in the European Union is the reduction of energy consumption. The European Union stated through the Directive on the Energy Performance of Buildings in 2010 [1] a reduction of 20% of the total Union energy consumption by the year 2020. Regarding to these demands, Romania as a European member, is struggling to comply to these measurements.

Our country has a larger percentage of detached houses than flats [2] and this percentage is increasing every year. Just for the first month of 2018, Romania has experienced an increase of 28,7% in the number of emitted building permits for residential buildings, compared to the same month of 2017 [3]. This significant expansion shows an increase for the need of new houses situated mostly next to the prolific urban areas which are developing fast. Thus, in the light of an emerging building market, a search for cost effective solutions that strive to attain a significant energy reduction is undergone. By the year 2020, all the new residential buildings have to comply to the nearly zero energy building standard [4]. However, the building market is still under development when it comes to offering alternative and economically competitive solutions for energy efficient houses, only the conventional



technologies complying with the existing building codes being the most accessible solutions on the market. Given the local situation described above, a natural question arises: what is the best approach when it comes to designing an affordable and energy-efficient new house in the context of the Romanian building market?

The last 20 years have revealed a common desire of the people embarking on the journey of constructing their house, a typical project brief which can be summarized as a 200 m² house (floor area), destined for a family of up to 4 persons [Table1]. Due to the particular seismic context, the most profitable load-bearing structures in the case of small private housing remains the masonry using large ceramic blocks, in-situ reinforced concrete and wooden roof structures. The purpose of the present paper is to evaluate several possible scenarios to the abovementioned project brief for an energy efficient single-family house and a cost optimal analysis, determining altogether which is the most profitable approach adapted to the Romanian building market context.

Table 1. List of interior spaces

Space name	Area [m ²]
Entry hall	5
Living room	35
Bathroom 1	5
Kitchen	20
Technical room	10
Storage room	8
Staircase	12
Office	12
Bedroom 1	16
Bedroom 2	16
Bathroom 2	7
Master bedroom	20
Total useful area	166
Circulation and interior wall area 20%	34
Total area without exterior walls	200

2. Proposed scenarios

The quest for defining the best approach in terms of energy efficiency and financial opportunity for satisfying the abovementioned project brief revolves around finding the cost optimal balance between the investment costs, mainly defined by the building proposed geometry and spatial composition, and the running and maintenance costs, defined by different energy performance benchmarks.

In order to examine a broad array of possibilities, we have several spatial configurations and levels of energy performance, that satisfy the typical project brief for a 200 m² useful floor area house for up to 4 people, on an average plot dimension of 650 m². Regular urban coefficients for the newly developed residential areas imply a maximum building footprint (built area) to site area ratio of 35-40%, and a gross floor area to site area ratio of maximum 0,7. Height of buildings is restricted to a maximum of ground floor and 1 storey.

2.1. Spatial approaches

Three spatial solutions are being considered, all corresponding to a constant floor area of 200 square meters and an approximately constant interior air volume of 507-530 cubic meters.

1. **Ground-floor house:** offers the best spatial connection of the interior spaces with the surrounding courtyard. For this approach we considered that the house would have a flat roof due to the larger area of the upper slab. A pitched roof in this case would be an inappropriate approach, because it would generate a higher unheated volume that would generate a higher construction and running costs. For this solution, we have taken into account that the free

height of the interior spaces would be 2,6m (this is the minimum required height in our national regulations). For the vertical facades, an estimated opening ratio has been considered, as follows: 10% for the North facing façade, 20% for the East and West façade and 30% for the south façade;

2. **One-storey flat roof house:** provides the smallest building footprint, reduced costs on foundation elements, and offers a compact building form. Also, here we have chosen to use the flat roof as a solution for the last slab, due to the compacticity of the volume. The free height of both floors that was took in account is 2,6m. For the facades we kept the percentage of the windows the same as for case 1;
3. **One storey house with attic:** provides an affordable solution for the given brief. For this approach, we have considered that the roof has a pitch of 45°. This would offer the best use of the interior space of the attic. Also, the height of the lateral walls for the first floor would be 1,2m to provide a plausible solution for the insertion of roof windows that would offer a visual connection between the interior and outer space. The free height between floors and percentage of windows remains the same for this given case.

2.2. Energy performance levels

The research takes into account three different energy performance levels, as defined by the national building codes and international certification systems, such as:

- a. **Reference house level:** the minimal energy performance level complying to the Romanian building codes, which consists of a moderate-insulated building envelope and a gas-individual heating system. The heating system consists of individual radiators in each room which are all connected to a central distribution system through copper piping. Ventilation is provided naturally and no cooling system was taken into account, due to the temperate climate of Timisoara; The electricity consumption is estimated as a result of the use of electrical appliances, a 270 kWh/month.
- b. **Low-e house level:** intermediate energy performance level given by the use of affordable building envelopes, which consists of a medium-insulated building envelope and a gas-individual heating system. The solution for this heating system consists of floor heating with PE-XA pipes, with heating control systems in each room, which are connected to a distribution system. Also, to this solution no cooling system was taken in account, ventilation is assured naturally and the electricity consumption remains the same as in case a;
- c. **Towards Passive house standard:** proficient energy performance level, complying to the passive house standard recommendations, which consists of a highly-insulated airtight building envelope and proficient glazing, a gas-individual heating system and a mechanical ventilation with heat recovery system. For this solution we applied the same floor heating system and in addition to this, a heat recovery system with a capacity of 300m³/h. No cooling system was taken into account, and the electricity remained the same as in previous cases.

For each of the energy performance levels, the building envelope components have been adapted around four main components, as seen in Figure 1: ground-floor slab, vertical exterior wall, flat roof or pitched roof slab and windows and glazing.

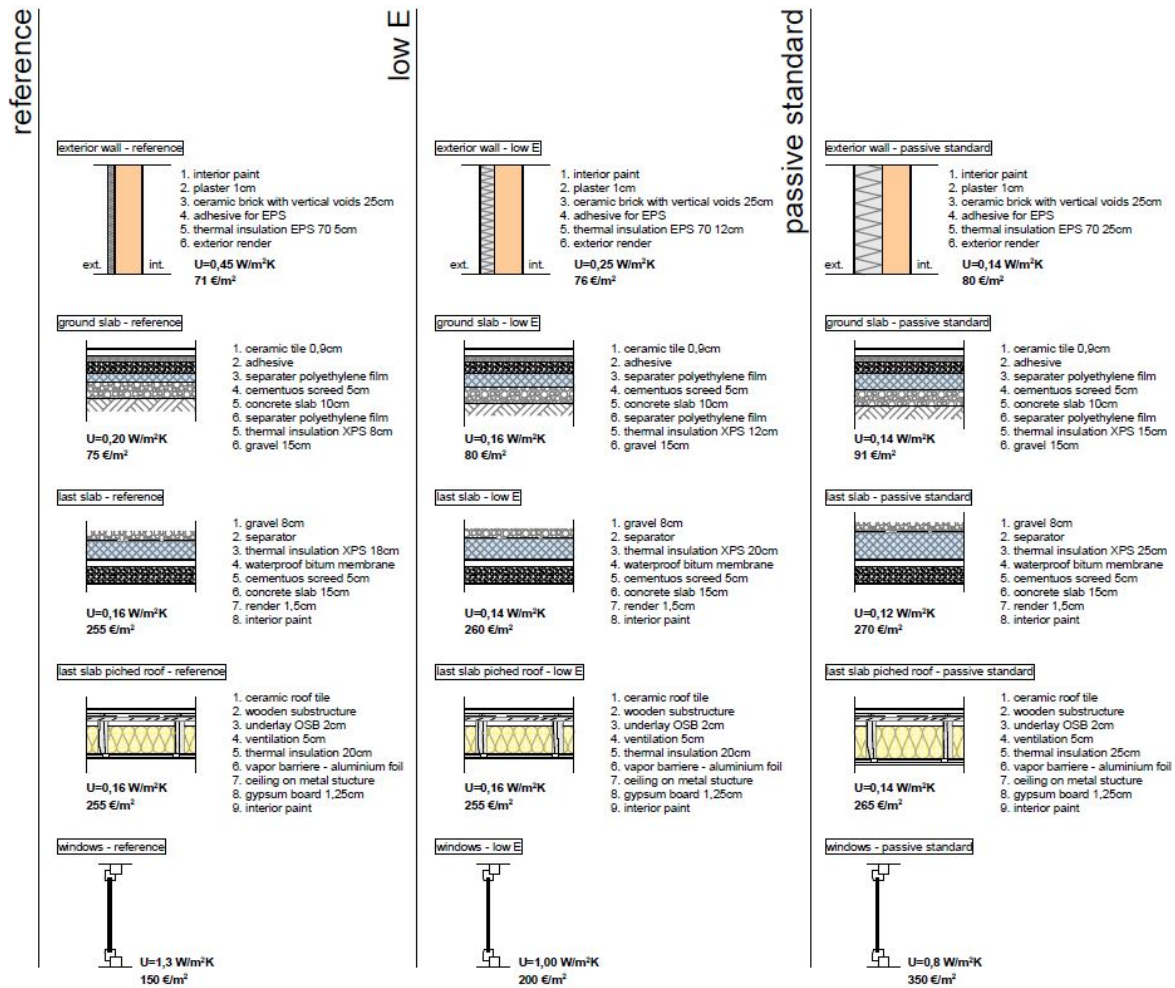


Figure 1. Costs of building envelope components for different energy performance levels

3. Cost optimal analysis method

Applying each energy performance level to each spatial solution, a total of 9 possible configurations are obtained, ranging from each house type being defined in each of the energy performance levels (see Figure 2). In order to analyze the costs associated to each of the configurations over a 30-year period, we have used the calculation relation described by Corgnati in [5], and also [6]. According to the cited sources, the net updated value of a building after N years of existence (VNA_n) is:

$$VNA = C_0 + \sum_{k=1}^3 C_{E_k} \sum_{t=1}^N \left(\frac{1+f_k}{1+i} \right)^t + C_M \sum_{t=1}^N \left(\frac{1}{1+i} \right)^t \quad (1)$$

where, in the present paper:

C_0 – initial investment cost, including structure, thermal envelope, finishes and building services, and occasional replacements costs [€];

C_E – annual cost of the used primary energy, for natural gas and electricity [€/year];

C_M – annual cost of maintenance [€/year];

f – annual rate of increase for the cost of primary energy –both for gas and electricity, a value of 0,05 has been taken into account;

i – annual rate of currency depreciation (0,04).

3.1. Estimation of investment costs

For each type of building envelope used to define the spatial solution corresponding to an energy performance level, we have associated an overall cost of used materials and execution. The costs associated with the building services have been estimated in accordance to the systems associated with each energy performance level described above. For the other remaining costs including interior finishing, we have taken into account proportional ratios also connected to the different energy performance levels, as explained in Tables 2 and 3:

Table 2. Ratio and percentage of building components to total building cost

	Reference level	Low-E Level	Passive House level
Building envelope	3.0 (60%)	4.0 (65%)	4.0 (50%)
Building services	1.0 (20%)	1.2 (20%)	3.0 (37%)
Interior finishes	1.0 (20%)	0.8 (15%)	1.0 (13%)
Total	5.0 (100%)	6.0 (100%)	8.0 (100%)

Table 3. Scenario geometric characteristics and investment values

Approaches		1.a	1.b	1.c	2.a	2.b	2.c	3.a	3.b	3.c
		ground floor house with flat roof - reference	ground floor house with flat roof - low E	ground floor house with flat roof - Passive standard	Two story house with flat roof - reference	Two story house with flat roof - low E	Two story house with flat roof - Passive standard	House with attic - reference	House with attic - low E	House with attic - Passive standard
walls	%	22.55	22.55	22.55	41.54	41.54	41.54	29.16	29.16	29.16
ground	%	35.91	35.91	35.91	24.04	24.04	24.04	25.56	25.56	25.56
Total Envelope Area /Last slab	%	35.91	35.91	35.91	24.04	24.04	24.04	34.00	34.00	34.00
Total Envelope Area /Windows	%	5.64	5.64	5.64	10.38	10.38	10.38	11.29	11.29	11.29
Total Envelope Area (A)	m ²	557	557	557	416	416	416	450	450	450
Exterior built volume	m ³	790	818	868	745	772	821	738	759	801
Interior Volume (Vi)	m ³	530	530	530	530	530	530	507	507	507
Copacticity (A/Vi)	m ⁻¹	1.05	1.05	1.05	0.78	0.78	0.78	0.89	0.89	0.89
G	m ² K/W	0.51	0.416	0.3512	0.5	0.389	0.32	0.485	0.39	0.33
Um	W/m ² K	0.31	0.22	0.164	0.39	0.26	0.178	0.36	0.25	0.18
Exterior walls	m ² North	40.5	40.5	40.5	57.6	57.6	57.6	32.4	32.4	32.4
	m ² East	26.8	26.8	26.8	35.2	35.2	35.2	36.8	36.8	36.8
	m ² South	31.5	31.5	31.5	44.8	44.8	44.8	25.2	25.2	25.2
	m ² West	26.8	26.8	26.8	35.2	35.2	35.2	36.8	36.8	36.8
	m ² Total	125.6	125.6	125.6	172.8	172.8	172.8	131.2	131.2	131.2
	% of total env.	23	23	23	42	42	42	29	29	29
	€/m ²	€ 71.00	€ 76.00	€ 80.00	€ 71.00	€ 76.00	€ 80.00	€ 71.00	€ 76.00	€ 80.00
Slab on ground	m ²	200	200	200	100	100	100	115	115	115
	% of total env.	36	36	36	24	24	24	26	26	26
	€/m ²	€ 75.00	€ 80.00	€ 91.00	€ 75.00	€ 80.00	€ 91.00	€ 67.00	€ 76.00	€ 82.00
Roof (Horizontal or Pitched at 45 degrees)	m ² North	0.0	0.0	0.0	0.0	0.0	0.0	40.5	40.5	40.5
	m ² East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	m ² South	0.0	0.0	0.0	0.0	0.0	0.0	31.5	31.5	31.5
	m ² West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	m ² Horizontal	200	200	200	100	100	100	81	81	81
	m ² Total	200	200	200	100	100	100	153	153	153
	% of total env.	36	36	36	24	24	24	34	34	34
Windows	€/m ²	€ 255.00	€ 260.00	€ 270.00	€ 255.00	€ 260.00	€ 270.00	€ 255.00	€ 255.00	€ 265.00
	% of envelope North	10%	10%	10%	10%	10%	10%	10%	10%	10%
	% of envelope East	20%	20%	20%	20%	20%	20%	20%	20%	20%
	% of envelope South	30%	30%	30%	30%	30%	30%	30%	30%	30%
	% of envelope West	20%	20%	20%	20%	20%	20%	20%	20%	20%
	m ²	31	31	31	43	43	43	51	51	51
	% of total env.	6	6	6	10	10	10	11	11	11
Total Envelope investment value	€/m ²	€ 150.00	€ 200.00	€ 350.00	€ 150.00	€ 200.00	€ 350.00	€ 150.00	€ 200.00	€ 350.00
	€	€ 79,627.60	€ 83,825.60	€ 93,238.00	€ 51,748.80	€ 55,772.80	€ 65,044.00	€ 63,655.20	€ 67,886.20	€ 78,251.00

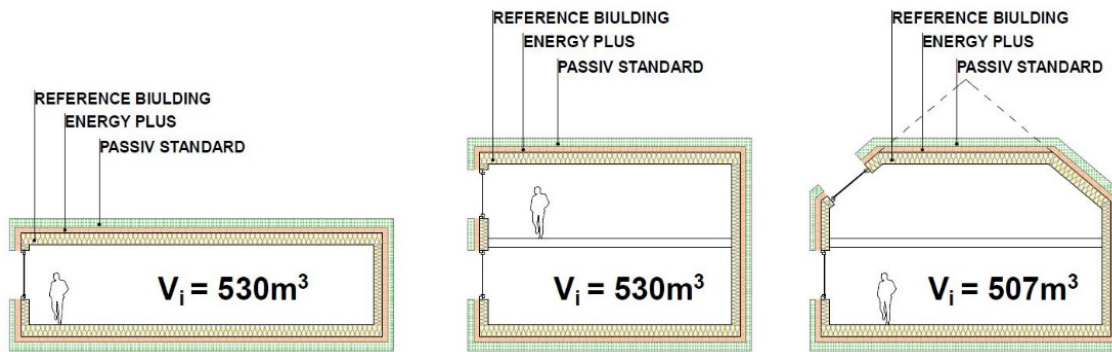


Figure 2. Schematic description of the 9 solutions approached

3.2. Estimation of running cost

This subsection will evaluate the yearly energy balance and primary energy costs for each of the 9 approaches.

In that respect the heating yield was determined taking into account the heat loss through the building envelope and also solar gains achieved through the proposed glazed surfaces. The heating requirements, including the domestic hot water consumption specific for a family for 4 and equal in all the evaluated cases, determines the gas consumption as a primary energy. Electricity consumption is providing for the use of electrical appliances and artificial lighting while also providing the energy for the mechanical ventilation in the passive standard scenarios. Maintenance costs are established as a result of regular maintenance of the building services, while occasional replacement of parts (short periods of warranty) are assimilated within the investment costs.

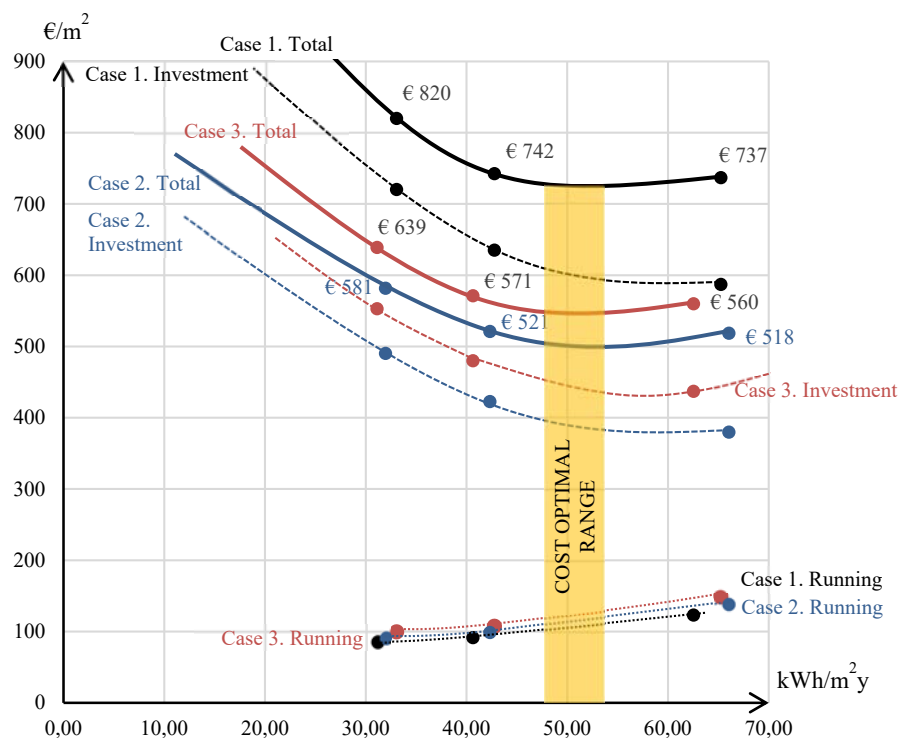


Figure 3. Cost optimal energy performance level for the three spatial solutions

4. Results and discussions

Based on the abovementioned methodology for the calculation of the updated net value of a building, a cost-optimal analysis was conducted on 30-year period, in order to establish which of the 9 approaches is most economically feasible for obtaining the highest energy efficiency level. The results can be seen in Figure 3. In the case of all the spatial solutions (ground-floor house, one-story flat roof house, one-story attic house), when taking into account the total costs generated by the houses over a 30-year span, a cost optimal range of energy efficiency arises, regardless of the form of the buildings. The results, therefore, imply that in the case of Romanian building market, the optimum goal-to-achieve for a feasible energy efficient home would be attained around the value of 50 kWh/m²y.

On the other hand, the total investment rises significantly when trying to accommodate the 200 m² of useful area in the volumetric case 1, describing a building with a compacticity of 1.05, in comparison with case 2 and 3 (an envelope area to volume ratio of 0.78 and 0.87 respectively).

When it comes to the return of the investment (see Figure 4), for the Romanian building market, none of the two energy-efficient scenarios can generate a lower overall cost than the reference level comprising to the existing building codes. This observation is valid for each of the spatial scenario considered in this paper.

However, when comparing the 9 configurations, one may observe the possibility of achieving a lower overall cost over a 30-year period than a reference building, by applying a more performant energy standard (low-E and even passive) only if opting for a more compact spatial solution. An overview of the construction costs for each of the parts (Figure 5) comprising the building envelope reveals that improving the degree of insulation differs as costs. In the case of windows and glazing, achieving the lowest thermal transmittance comes at the highest price/m². When it comes to the roof slabs or roof with attic, a greater cost spent on a low-transmittance element would bring benefits of up to 200%, while, from a point onward, further investment will not generate significant improvements in thermal transmittance values. The cheapest improvement is obtained for the ground slab.

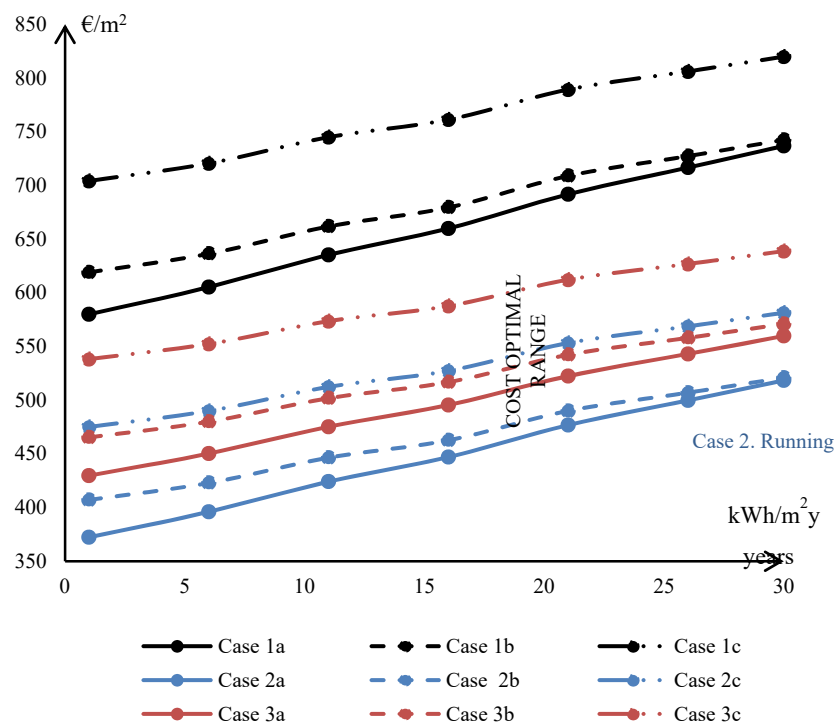


Figure 4. Return of investment

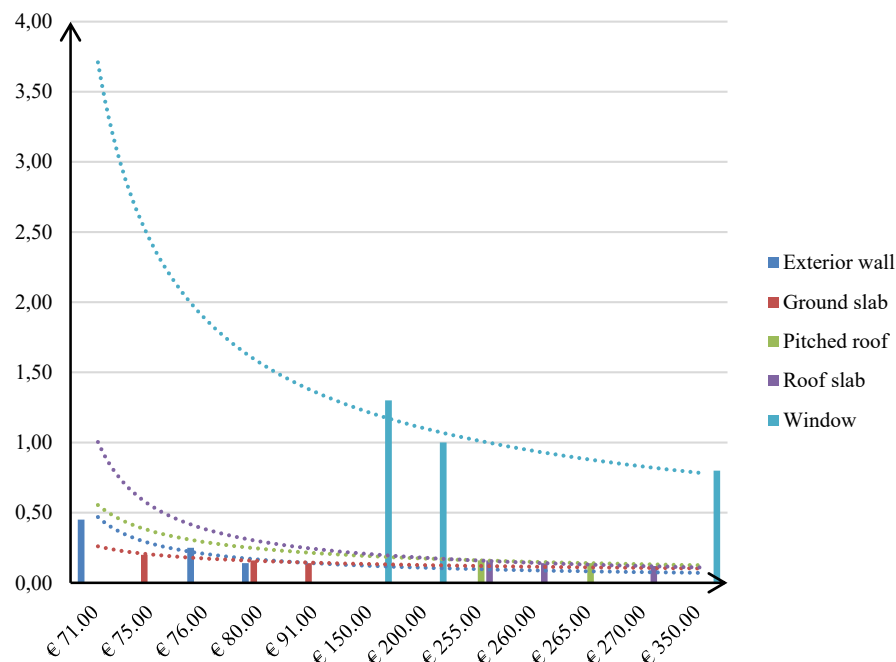


Figure 5. Cost of building elements / U Value

5. Conclusions

The goal of the present paper was to determine the best spatial, economic and constructive approach in order to obtain a cost optimal energy efficient 200 m² home. Based on an overview of the total costs generated by 9 different technical and spatial configurations of the house over a period of 30 years, a few possible conclusions can be revealed:

- the cost optimal performance level might not correspond to the best or worst energy performance levels, but rather to a mean solution, but different in respect to each spatial solution; In the studied cases, irrespective of the spatial solution, it was demonstrated that an achievable and cost-effective level of energy performance is obtained around the value of approximately 50 kWh/m²y;
- When quantifying the cost per building envelope, the smallest investment costs of the building are achieved when the volumetric approach offers the smallest corresponding building compacticity value (envelope area to volume ratio); At the same time, the overall costs per 30 years are reciprocally higher for the building volumes having a larger compacticity;
- Obtaining same insulation value improvements might cost differently for different parts of the building envelope, thus favouring particular geometric approaches for energy efficient solutions (those that present smaller roof surfaces, such as the one-story house with flat roof or attic, will behave better with the energy consumption than others that have large areas of this part of the building envelope e.g. the flat-roof ground house).
- When targeting to achieve the passive house standard, following the general recommendations of insulating the building envelopes and windows, of assuring the recommended airtightness, proves to be insufficient to obtain the energy consumption level of 15 kWh/m²y; This furthermore proves that a careful design of all the details (reducing thermal bridges, solar gains etc.) is essential in achieving very high standards of energy consumption.

References

- [1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
- [2] Eurostat, “Distribution of population by dwelling type”, available from: <http://ec.europa.eu>, 2015, (accessed on 24.03.2018).
- [3] National Institute of Statistics, Romania, “Press release No. 48 from 28.02.2018”, available from <http://insse.ro>, 2018, (accessed on 24.03.2018).
- [4] The Official Gazette of Romania, Law 372/2016 The energy performance of buildings, 27.01.2016.
- [5] C. Becchio, A. Buonomano, F. Cappelletti, S. Corgnati, D. Tiziano, A. Palombo, F. Peron, P. Romagnoni, “Towards nZEBs: experiences in Italy”, *12th Rehva World Congress*, 2016.
- [6] The Methodology of calculation of energy performance of buildings, (“Metodologia de calcul al performantei energetice a cladirilor”), 2009.