Cost and Energy Efficient Envelope Systems for a Single-Family House in Timisoara, Romania

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Abstract. Over the last decade, Romania has faced a rapid expansion in the residential sector. The need for housing has increased significantly next to the ever-developing urban areas. One of the main targets for our country is to reduce the total energy consumption stipulated by the Energy Performance of Building Directive (EPBD). The main purpose of the study is to determine a comparative solution of the building envelope for a single-family house with a given net area and interior volume suited for a family with two adults and two children. The study is applied on a masonry two story house with continuous concrete foundations and a flat roof. This kind of scenario fits the local seismic building codes and currently, is the most accessible solution on the market. According to the national energy efficiency building requirements two different envelope systems are considered: monolithic wall (autoclaved aerated blocks) and multi-layered wall (large ceramic blocks with additional insulation), both having the same U value required by the above-mentioned code. Because the monolithic wall solution should have a shorter execution period than a multi-layered component, we intent to compare cost-efficiency scenarios of the two systems given local building standards. In both cases, the masonry acts as the main structural component of the system with similar concrete components. Because, in Romania, the most used thermal envelope system is based on polystyrene (EPS), a material with high embodied energy, the paper studies alternative solutions for residential buildings, with lower impact on the surrounding environment.

1. Introduction
The building sector is one of the main factors in the increased CO2 levels and greenhouse gas emissions (GHG) [1-3] Therefore one of the main concerns of the European Union is to make this area more energy efficient. According to the 20-20-20 Directive on the Energy Performance of Buildings, from 2010 [4], the reduction by 20% of the total amount of energy consumption by the year of 2020 is mandatory. In order to meet the requirements each country has devised their own energy efficiency plan. As a member of the European Union, Romania needs also to meet the stated requirements, therefore the local energy codes [5] have been revised over the last years, as seen in Table 1.

Considering local context, a case-study on a single-family house for a family of four members (two adults and two children) has been carried out. Due to local seismic codes, the most common housing typologies are based on masonry structures with continuous concrete foundations. Considering
energy efficiency, the best solutions would be the ones with an optimal volume to envelope ratio. Due to this fact, we opted for a flat roof housing typology that fits this context best.

Table 1 Romanian codes on thermal resistance of building elements

| Year | Code     | Outer walls | Flat roofs | Floor/basement |
|------|----------|-------------|------------|----------------|
| 1962 | 6741-61  | 0.76        | 0.96       | 0.82           |
| 1984 | NP15-84  | 1.2         | 1.55       | 1.08           |
| 1997 | C107/3-1997 | 1.09     | 1.46       | 1.25           |
| 2010 | C107/3-1997 | 1.80     | 5.00       | 2.90           |

Given the local situation described above, a natural question arises: what is the best approach when it comes to design the exterior wall from the energy-efficiency point of view in contrast with cost for the Romanian building market. The purpose of the present paper is to evaluate the best solutions for the exterior walls of a single-family house in order to obtain the most profitable approach adapted to the Romanian building market context.

The base model is a hypothetical two-storey scenario with 89.7 sqm/storey built area as shown below in Figure 1 and Table 2.

Figure 1. Base model views
Table 2. Floor space areas

| Room          | Usable area [sqm] | Room          | Usable area [sqm] |
|---------------|-------------------|---------------|-------------------|
| **Ground floor** |                   | **First floor** |                   |
| Technical room | 5.97              | Hall          | 9.88              |
| Bathroom      | 3.59              | Bathroom      | 4.47              |
| Entry hall    | 7.64              | Child room 1  | 12.72             |
| Kitchen       | 17.27             | Child room 2  | 13.80             |
| Storage       | 3.79              | Master bedroom| 17.05             |
| Living room   | 23.82             |               |                   |

The house was so designed, that all the main rooms face the south façade in order to obtain as much sunlight as possible. In order to avoid overheating during summer al south-facing windows are protected against direct sunlight, but for the winter period the house speculatesthe direct energy gain from the sun’s radiation. The house is divided so that the dorms are at the first floor, and the living area with the kitchen is at the ground floor. The interior height of the rooms is about 2.6m. This height would correspond to the minim given by the national building codes. The above-mentioned approach would fit most of the single-family houses build in Romania.

2. Proposed scenarios
To meet the above stated, two possible scenarios were identified. The first option is based on a multi-layered wall (25 cm thick large ceramic blocks with additional 15 cm EPS insulation), the most used solution in our country. The second consists of a monolithic wall (40 cm thick autoclaved aerated blocks). Both scenarios have the similar U-values in order to obtain similar results.

For both cases and due to local context, the evaluation was based on identifying the best solution for the outer walls. In both scenarios the upper and lower slabs were kept with the same layer composition, according to Romanian energy efficiency standard codes. Also, the windows and doors have the same parameters.

The heat protection of a room is influenced by several factors, but essentially by the direct solar radiation through windows and the total amount of heat storage capacity of the elements. Other factors involved in the energy balance proved to be important, such as:

- phase shift: the time after which the peak afternoon temperature reaches the interior side of the component;
- amplitude attenuation: the attenuation of the temperature wave when passing through the façade system: a value of 10 implies that the temperature on the outside varies 10x stronger than on the inside, e.g. outside 15-35 °C, inside 24-26°C;
- temperature amplitude ratio (TAV): the reciprocal of the amplitude attenuation.

The thermal analysis was carried out using an online U-value calculator (Ubakus) [6] and Graphisoft Archicad 21 energy evaluator add-on [7]. For the simulations the following data have been considered and applied on a base model located in the city of Timisoara, Romania:

2.1. Multi-layered wall system evaluation and results
This approach is the most used construction method in our country. It consists of exterior structural walls built out of large ceramic blocks with a total thickness of 25cm and a 1cm layer of plaster. The national seismic codes require at each corner or intersection of the structural walls, concrete pillars so that it can form a structural frame around the masonry to improve its structural resistance. Due to this condition, this construction method does not comply with the energy-efficiency standards. In order to
do so it requires an additional exterior thermal insulation. The most used external insulation in our country for the exterior walls is polystyrene EPS

In this scenario the simulation proves that the thermal protection is $U=0.193 \text{ W/m}^2\text{K}$. Furthermore, the heat storage capacity of the element is 259 $\text{kJ/ m}^2\text{K}$ with the thermal capacity of the inner layers at 210 $\text{kJ/ m}^2\text{K}$ and the overall thermal resistance of 5.167 $\text{m}^2\text{K}/\text{W}$. This value is almost three times greater than the current values according to current Romanian norms. Phase shift is achieved after 16.5 hours with an amplitude attenuation of 7.9 and TAV 0.004.

**Figure 2.** Base model views

**Table 3.** Envelope layers

| Material                          | $\lambda$ [W/mK] | $R$ [m²K/W] | Temperature [°C] | Weight [kg/m²] |
|----------------------------------|------------------|-------------|-----------------|----------------|
| Thermal contact resistance       | 0.130            | 18.3        | 20.0            |                |
| 1.5 cm cement render             | 1.400            | 0.011       | 18.3            | 18.3           | 30.0           |
| 25 cm Porotherm block            | 0.202            | 1.238       | 10.1            | 18.3           | 212.5          |
| 15 cm EPS rigid panels           | 0.040            | 3.750       | -14.7           | 10.1           | 3.0            |
| 0.8 cm Adhesive/ armour render   | 1.000            | 0.008       | -14.7           | -14.7          | 12.0           |
| Thermal contact resistance       | 0.040            | -15.0       | -14.7           | 257.5          |
| 42.3 cm Thermal contact resistance| 5.176            |             |                 |                |

Thermal contact resistances according to DIN 6946 for the $U$-value calculation. $R_{si}=0.25$ and $R_{se}=0.04$ according to DIN 4108-3 were used for moisture proofing and temperature profile.
In order to evaluate the energy balance of the four systems the following operation profiles have been introduced:

- human heat gain: 70W per user;
- service hot-water load: 60l/day per user;
- humidity load: 2g/day per user;
- usage rate: 6264 hours/year;
- lighting: LEDs;
- heating: 8500W nominal capacity floor space heating system. Control type: temperature controlled with indoor sensors.

The charts show the amount of energy the building emits (bottom part), as well as the building’s supplied energy: the amount of energy it absorbs from the environment and its own internal heat sources (top part), by month (in this case) or week, depending on the user preferences.

According to the energy balance equation, the Emitted energy and Supplied energy bars must be equal every month. The vertical axis of the chart shows an energy scale. Along the horizontal axis, the twelve months of the year are shown.

![Graph showing energy balance](image)

**Figure 3.** Multi-layered wall energy evaluation graph

### 2.2. Monolithic wall system evaluation and results

This construction method is less familiar to the local construction market due to the higher construction cost. It consists out of autoclaved aerated blocks with a thickness of 40cm. The layer of plaster between the rows is very small in order to reduce the energy loss with the exterior. Due to the seismic codes this construction system requires also concrete pillars at the corners and at the intersection of structural walls. Because of the higher thickness of the exterior wall (40cm), the concrete columns with a dimension of 25x25cm can be easily be embeded in the thickness of the wall reducing thermal heat loss with the exterior.

In this case, the resulted thermal protection is $U=0,187\ W/m^2K$. Also, a heat storage capacity of the element is $149\ kJ/\ m^2K$ with a value for thermal capacity of inner layers at $90\ kJ/\ m^2$. The thermal resistance of the component is $5,385\ m^2K/W$. Phase shift takes 18 hours, TAV 0,006.
Figure 4. Base model views

Table 4. Envelope layers

| Material                        | λ [W/mK] | R [m²K/W] | Temperature [°C] | Weight [kg/m²] |
|--------------------------------|----------|-----------|------------------|----------------|
| Thermal contact resistance     | 0.130    |           | 18.4             | 20.0           |
| 1.5 cm Lime Cement render      | 1.000    | 0.015     | 18.3             | 18.4           | 27.0 |
| 40 cm Ytong Planblock W PP 1.6-0.30 | 0.080 | 5.00      | -13.5            | 18.3           | 120.0 |
| 0.8 cm Cement render           | 0.040    | 0.200     | -14.7            | 18.5           | 2.0  |
| 42.3 cm Thermal contact resistance | 0.040 | 0.040     | -15.0            | -14.7          | 149  |

Thermal contact resistances according to DIN 6946 for the U-value calculation. Rsi=0.25 and Rse=0.04 according to DIN 4108-3 were used for moisture proofing and temperature profile.
In this case we used the same parameters mentioned above for the energy evaluation. The results are shown below in Figure 5.
3. Cost evaluation

After a first cost evaluation we concluded that the cost/sqm for the multi-layered solution would be around 52.57 euro, and for the monolithic proposal would be higher around 67.46 euros. The calculations were made with national evaluation methods, based on the local construction market.

| Scenarios                | Euro/sqm | Total sqm of facades | Total cost [euro] |
|--------------------------|----------|----------------------|-------------------|
| Multi-layered external wall | 52.27    | 207                  | 10881.99          |
| Monolithic external wall  | 67.46    | 207                  | 13964.22          |

We can observe that the monolithic proposal is 28.32% more expensive than the multi-layered solution.

4. Conclusions

It can be observed that the multi-layered system has a higher total weight value, which will significantly influence the concrete foundations cross-sections and quantity of steel for reinforcement. However, this aspect will be elaborated further in future works.

Figures 2 and 4 (humidity curve) show that the monolithic system generates no condensation, therefore it will not affect the overall thermal protection capacity of the envelope. Also, the quality of indoor air is better. By using other thermal insulating materials with a lower vapour diffusion coefficient (e.g. mineral wool), the multi-layered system will perform better but with higher expenses.

| Envelope        | Overall thermal resistance [m²K/W] | Lowest net heating energy balance [kWh/a] | Heat storage capacity [kJ/m²K] | Thermal capacity of inner layers [kJ/m²K] | Phase shift [hours] | Amplitude attenuation | TAV |
|-----------------|-----------------------------------|------------------------------------------|--------------------------------|------------------------------------------|---------------------|-----------------------|-----|
| Multi-layered   | 5.17                              | 3671.7                                   | 259                            | 210                                      | 16.5                | >100                  | 0.004 |
| Monolithic      | 5.38                              | 3617.0                                   | 149                            | 90                                       | 18                  | >100                  | 0.006 |
In case of the multi-layered envelope, we observe that the total heat capacity is higher than the monolithic one. Thus, this option is more efficient during significant temperature drops. However, the monolithic system can be improved by using additional phase shift materials on the inside face.

The base thickness of the monolithic system was used as a starting point for the analysis. Both systems had to have similar U-values in order to obtain concrete data. It can be observed that for the both systems the final thickness would be around 42 cm. This means that the built area in both cases is the same.

Considering execution phases, which affect the overall cost of the building, the multi-layered option takes more time to materialize but it is cheaper then a monolithic option.

With higher cost, a better overall performance is offered by the monolithic outer walls.

References
[1] The Chartered Institute of Building- CIOB, Sustainability and Construction, www.ciob.org.uk.
[2] UIA 2009. Copenhagen Declaration, Declaration on Sustainability and Cultural Diversity, Approval by the UIA World Congress in June 2008, www.uia-architectes.org
[3] European Construction Technology Platform, Vision 2030 & Strategic Research Agenda, Focus Area Cities and Buildings, 2005
[4] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
[5] C107/1-3/1997 – Romanian standard for the computation of global thermal insulation coefficients for civil buildings, ASRO, 1997.
[6] Ubakus, https://www.ubakus.de/u-wert-rechner/?
[7] Graphisoft ARCHICAD 21.0.0 build 3005, http://www.graphisoft.com/archicad/