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# LIFE CYCLE COST ANALYSIS FOR REFERENCE PROTOTYPE BUILDING IN ALTERNATIVES OF SILICATE AND WOOD-BASED STRUCTURE

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## ABSTRACT

The paper is aimed at the use of the LCC method and quantification of costs for alternative silicate and wood-based composition of exterior walls in reference building. YTONG and Porotherm were selected as the materials for the silicate detached house, while for the wood-based structure, the most often used outside wall compositions made by Slovak producers were studied. The methodology was applied in accordance with the standard EN 15459, 15978 within the monitored life cycle stage cradle to use, while considering the realistic average interest rate of 3% p.a., inflation rate of 2.5% and 30-year lifespan. Although the investment costs are higher, the findings confirm that a well-made wood-based structure can, during its operation, save costs of 10−15 €/month. After considering the other potential benefits of wood-based structures and mainly after taking account their environmental aspect, the wood-based structures provide a solution for moving the building industry towards the sustainability goals.

**Keywords:** life cycle costing, wooden house, silicate house, operation costs.

## INTRODUCTION

The issue of securing one of the basic live needs – housing, is the topic for every one of us. This topic is associated with the desire for building one’s independence and is even stronger when deciding to raise a family. There are several options for fulfilling this need. According to our current survey, approx. 30% of people in Slovakia decide to build a house. The rest decide to buy or rent a flat or share the flat or house with parents or friends. The current trend in housing is building a wood-based detached house. It is an ecological, fast and economically interesting method of building structures. GOSSELIN *et al.* (2016) state that main motivation for using wood in buildings is linked with sustainability, technical aspects, cost reduction, building erection speed and aesthetics. ŠTEFKO *et al.* (2014) and also MAŤOVÁ and KAPUTA (2018) confirm these facts. There are, however, many prejudices against the wood-based alternatives which eventually promote traditional silicate buildings. Results of the study by ÖSTMAN *et al.* (2018), HU *et al.* (2016), DRAGHICI and MAICAN (2018) and also GOSSELIN *et al.* (2016) pointed out to the questionable technical aspects of wood (acoustic performance, stability and wood shrinkage, humidity, protection against insects, wind, rot, water, earthquakes) and other main barriers (national building codes, cost, material durability, fire resistance). Under the conditions of Slovak producers, the use of domestic renewable raw material for evaluation and availability is also a problem. This is stated in the studies GEJDOŠ and DANIHELOVÁ (2015) and also GEJDOŠ *et al.* (2018). In Slovakia, it can be estimated that wood-based structures comprise less than 10% of new constructions. Although a slight increase has been recorded in the recent years, the potential in this field in Slovakia has not still been used to its fullest. ŠUŠTIAKOVÁ (2016) compares the situation in Slovakia with Austria, where the national programmes encourage the increase of the ratio of wood-based structures to 80–90%. Similar ratio can be observed in Scandinavia or North America. When deciding about the construction of a house regardless the form (silicate or wood-based structure), an important role is played by the limited sources of financing. It is important to consider not only the investment required at the time of construction, but also the operating costs or costs associated with the house disposal, which will be required in the future. Apparently, when making the decision, one must consider also the costs associated with the whole life cycle of a structure. The method Life Cycle Costing (LCC) is suitable for such type of decision making.

So that the investors are able to decide which type of house they will select only after familiarising with the basic technical and technological characteristics of the alternatives. Further aspects that are taken into account include the principles of healthy, comfortable and modern housing. Considering the basic requirements for constructing a house, the attention is paid mainly to the issue associated with the energy demands. According to the standard EN 15 459, from 1 January 2021 all new constructions will need to approach the zero energy consumption after deducting the energy obtained from the renewable resources. For a new structure to meet the conditions of the energy certificate (Directive no. 2010/31/EU on the energy performance of buildings), the investor has to consider the increased investment costs. Along with the energy certification of buildings, this directive introduces cost effective measures for energy performance of buildings connected to decreasing the energy demands for operating the buildings affecting the primary energy and $CO_2$ emissions. These measures should secure meeting the cost optimal levels of minimum requirements for energy performance of buildings. Wood-based structures in their finished state absorb $CO_2$ during their whole life cycle. In addition, when they are compared with other construction materials, they are produced in a low-energy production process with minimum emission. This fact was confirmed also in the studies of GUSTAVSSON, JOELSSON and SATHRE (2010), BIN and PARKER (2012) and GUSTAVSSON *et al.* (2017).

Following the previous claims it can be stated that currently the main challenge of the building industry, along with fulfilling the essential preferences of building users, is mainly the effort to reduce the energy demands of buildings. Fulfilling this objective gradually results not only in decreasing the demands for financing the building operation, but also decreasing the amount of emissions and thus improving the environment. Correct decisions regarding the thermal performance of buildings during their build up decrease the future operating costs.

The climate conditions of our region cause that the highest energy consumption is associated with covering the thermal losses and decreasing the thermal gains, i.e. heating, cooling and ventilating. The amount of such energy demand is according to the EN 15459-1:2017 Energy performance of buildings affected mainly by: urban design and orientation of the structure, architectural design, structural concepts and physical and thermal performance of the building and technical parameters of the equipment providing the building microclimate optimisation. The future building owner has to make the decision on the amount of current costs for planned investment and thus influence the amount of future annual operating costs. They have to decide either to invest more into building the structure, which will eventually lead to decreased operating costs or they select a cheaper building process associated with higher annual operating costs. With the return on investment it is inevitable to consider also the inflation change of energy costs increase. In order to make a qualified decision it is necessary to follow 5 steps according to the EN 15 459: financial analysis (impact of economic parameters), financial prediction of individual build up variants (calculations), determining the discount rate, quantification of the current life cycle cost value for each alternative, recalculation of annual costs of LCC via annuity current value for each alternative.

According to the law on energy performance of buildings No. 555/2005 the cost effective level means the level of energy performance of buildings leading to the lowest costs during the estimated economic cycle of the building. Since the law orders to determine the cost optimum for the whole building life cycle, the use of LCC analysis is an inevitable part of the economic assessment of the cost optimum. According to PELZETER (2007) the LCC analysis can provide actual information on the preferences regarding the individual building technologies for building houses exclusively from the economic aspect during their whole life cycle. Already the name of the analysis implies that it is the calculation focused on longer time period, i.e. more than 5 years. The Life Cycle Costing method is, according to AGUACIL *et al.* (2017) and BECCHIO *et al.* (2015), a summarising view of all costs and expenses associated with the building expressed in form of standard economic calculations relative to the actual value as per the day of decision making. It means that while deciding today about the investment, one is trying to take into consideration also the end of the building lifecycle. Such view allows us to consider the acquisition price as well as the future expenses and costs. Quite complex issue, that needs to be focused on according to the studies of MORTENSEN *et al.* (2014), NEROUTSOU and CROXFORD (2016) and NIEMILÄ *et al.* (2017), is determining the length of the life cycle. The standard mentions the basic procedures. Nevertheless, in the case of such a complex product as building of a house is, comprised of elements with various lifespan lengths, affected also by the external depreciation, determining the lifespan length is much more difficult. In case of determining the lifespan of buildings it is important to consider this issue responsibly in order to get real results.

Therefore, the main aim of this paper is to use the LCC method and subsequently quantify the investment and operating costs for Reference Prototype Building for alternative compositions of exterior walls comparing the silicate structure and wood-based structure.

## MATERIALS AND METHODS

The present study deals with constructing a house in two basic forms, one being the traditional silicate structure and the other one wood-based structure. From the results of an on-line questionnaire survey (https://www.survio.com/survey/d/H9O7W5K1K8K6N3H5R) presented in the study by DEBNÁR and POTKÁNY (2016), it is possible to characterise the Reference Prototype Building (RPB), which considers the current preferences of the potential customer. A more detailed description of the layout and character of the RPD are illustrated in Figure 1. The present study deals with constructing a house in two basic forms, one being the traditional silicate structure and the other one wood-based structure. The method of constructing is affected by the selected form as well as by the used materials and construction processes. After careful consideration of all aspects, two alternatives were selected – silicate structure with load bearing materials YTONG and Porotherm (alternative A1 and A2, Figure 2) and 3 various compositions of exterior walls (alternatives A3–A5) for a wood-based structure. These alternatives used the outside wall compositions certified and preferred by prominent producers of wood-based structures houses in Slovakia (Figure 3).

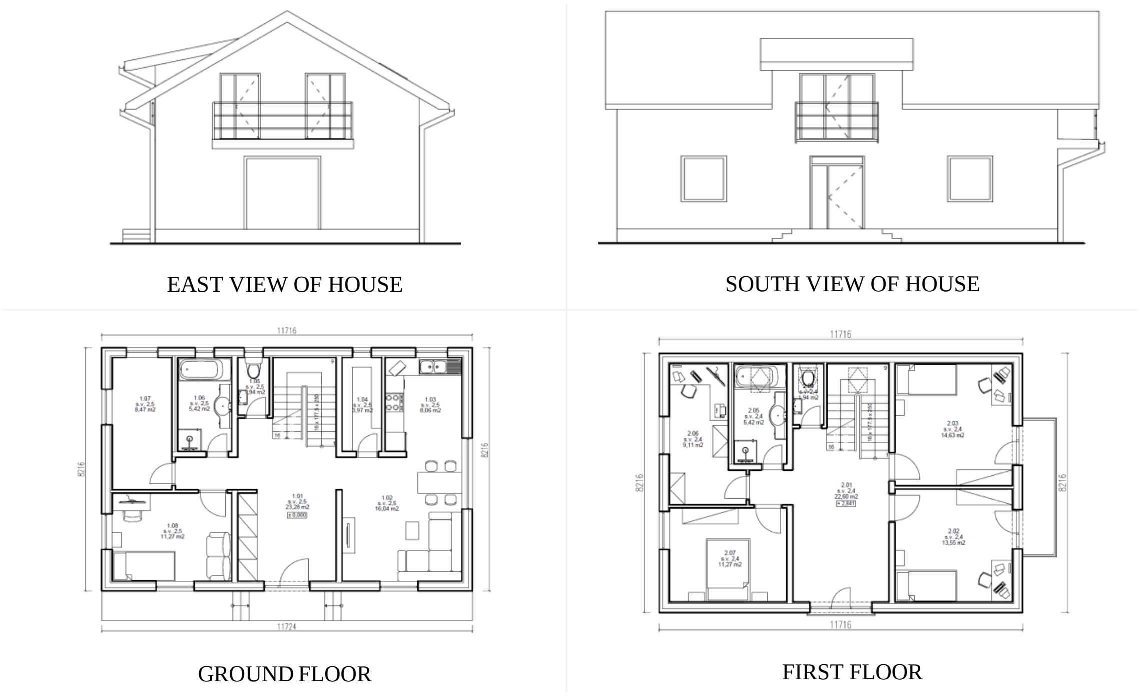



**Fig. 1 Layout and character description of the Reference Prototype Building.**

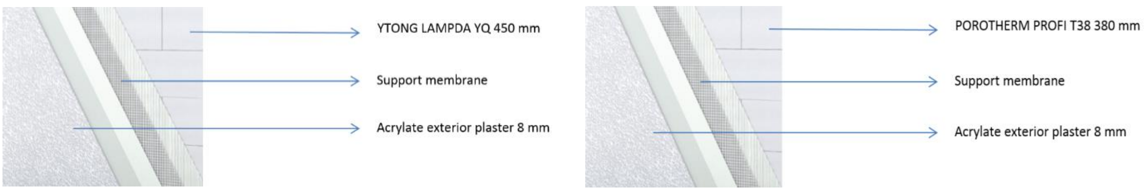



**Fig. 2 Components of exterior walls for alternatives A1-A2.**


1. white paint
2. textured wallpaper
3. gypsum fibreboard, 15 mm
4. installation gap, 60mm
5. Fermacell board, 12.5 mm
6. spruce wood frame construction with insulation, 140 mm
7. wood fibreboard insulation, 60 mm
8. mesh with putty
9. plaster, 3 mm

1. white paint
2. textured wallpaper
3.gypsum fibreboard, 15 mm
4. installation gap, 60mm
5. Fermacell board, 12.5 mm
6. spruce wood frame construction with insulation, 140 mm
7. wood fibreboard insulation, 100 mm
8. mesh with putty
9. plaster, 3mm

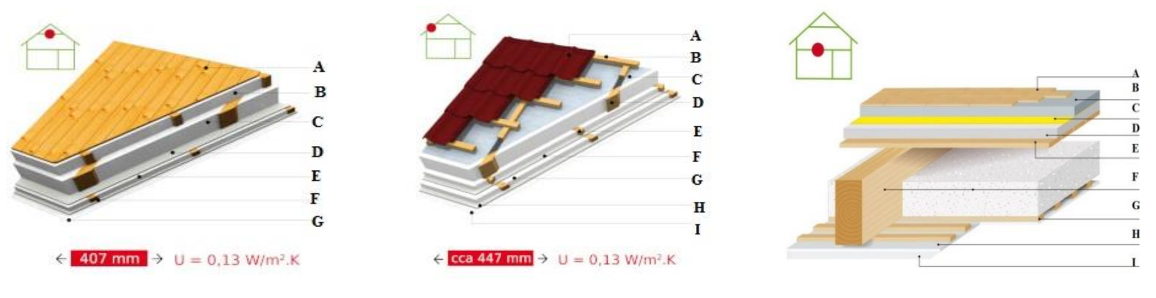
1. white paint
2. textured wallpaper
3. gypsum fibreboard, 15 mm
4. installation gap, 60mm
5. Fermacell board, 12.5 mm
6. spruce wood frame construction with insulation, 140 mm
7. wood grill with mineral wool, 80mm
8. wood fibreboard insulation, 120 mm
9. mesh with putty
10. plaster, 3 mm

**Fig. 3 Components of exterior walls for alternatives A3-A5.**

**Tab. 1 General information on the Reference Prototype Building.**

| Specification | Alternatives | | | | |
|---|---|---|---|---|---|
| | **A1** | **A2** | **A3** | **A4** | **A5** |
| Usable floor area ($m^2$) | 146 | 146 | 156 | 156 | 156 |
| Base plate area ($m^2$) | 92 (11.5x8) | 92 (11.5x8) | 92 (11.5x8) | 92 (11.5x8) | 92 (11.5x8) |
| Household size (no. of people) | 4-5 | 4-5 | 4-5 | 4-5 | 4-5 |
| Number of rooms | **5** | **5** | **5** | **5** | **5** |
| Number of floors | 2 | 2 | 2 | 2 | 2 |
| Type of roof | Saddle roof | Saddle roof | Saddle roof | Saddle roof | Saddle roof |
| Construction type | Porotherm | YTONG S | Timber frame | Timber frame | Timber frame |
| Indoor temperature (°C) | 20 | 20 | 20 | 20 | 20 |
| Air exchange rate ($h^{-1}$) | 1 | 1 | 1 | 1 | 1 |
| Heat transfer coefficient External wall U [$W/m^2K$] | 0.161 | 0.179 | 0.161 | 0.141 | 0.109 |
| Roof U [$W/m^2K$] | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Ground floor U [$W/m^2K$] | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| First floor ceiling U [$W/m^2K$] | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Triple glass Ug [$W/m^2K$] | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 |
| Windows $U_W$ [ $W/m^2K$ ] | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 |
| Energy consumption [kW/h/year] | 5445 | 6095 | 5445 | 5033 | 4391 |
| Basic information on financing | Loan/ own source (80%: 20%); average interest rate of loan is 3.0% p.a. in realistic prediction and time of loan is 30 years. | | | | |

Figure 4 illustrates the structure of roof construction elements and floor in the RPD, while Table 1 provides the input information for carrying out the analysis of life cycle for individual alternatives.




A. concrete roofing felt
B. laths
C. diffusion foil
D. wood roof truss construction with insulation, 200 mm
E. wood Grill with mineral wool, 60 mm
F. Fermacell board, 12.5 mm
G. wood grill with mineral wool, 60 mm
H. plasterboard, 12.5 mm
I. paint

A. wood decking, 22 mm
B. wood Grill with mineral wool, 80 mm
C. wood ceiling construction with mineral wool, 220 mm
D. Fermacell board, 12.5 mm
E. wood grill with mineral wool, 60 mm
F. plasterboard, 12.5 mm
G. paint

A. laminate floor, 12 mm
B. concrete layer with heating system, 50 mm
C. PE protective film
D. mineral wool, 40 mm
E. wood decking, 22 mm
F. wood ceiling beams with insulation, 220 mm
G. wood grill, 18 mm
H. plasterboard, 12.5 mm
I. paint

**Fig. 4 Components of roof and ceiling for the Reference Prototype Building.**

The main heating source selected was represented by the currently most preferred type of a gas condensing boiler. In order to determine the energy consumption per year equation 1 was used. This equation is defined by the standard STN 73 0540-2/Z1: 2016:

$$Q_h = 82.1 \text{ x } (HT + HV) - 0.95 \text{ x } (Q_s + Q_i) \quad (1)$$

Where: $Q_h$ is the heat required for heating [kWh/ year], HT is the thermal loss caused by heating, HV is the heat loss caused by ventilation, $Q_s$ represents the passive solar gains and $Q_i$ are free heat gains from people associated with the structure orientation and window size. Thermal loss of the heating system (Heating system efficiency) can be quantified using the equation 2:

$$Q_l = Q_h \times (1 - A \times B \times C) \qquad (2)$$

Where A is the efficiency of the floor heating system, B is the distribution system performance = 0.97 and C is the operation of the heat production system (gas condensing boiler) = 0.98.

The overall energy requirement for heating (Q) can be determined according to the equation 3:

$$Q = Q_h + Q_l \qquad (3)$$

Where $Q_h$ is the energy consumption [Kw/h], and $Q_l$ is the heat loss of the heating system [Kw/h].

LCC calculation, according to the STN EN 15 459, tries to consider all costs which were generated during the course of the whole product life cycle. In the present case, the product is the building of a house. The scheme of the life cycle is presented in Figure 5. The individual phases take into account also the time of generating individual expenses and the type of expenses. For the sake of the present study, the phases cradle to use of the building (Product, Construction and Use Stage) are evaluated. In a simplified form, individual cost groups can be defined as investment costs and operating costs. When quantifying the costs associated with the stages maintenance, repair, replacement and refurbishment, these costs can be considered irrelevant, since in the case of all alternatives they represent the same value (e.g. window maintenance, heating element replacement, bathroom fixtures).

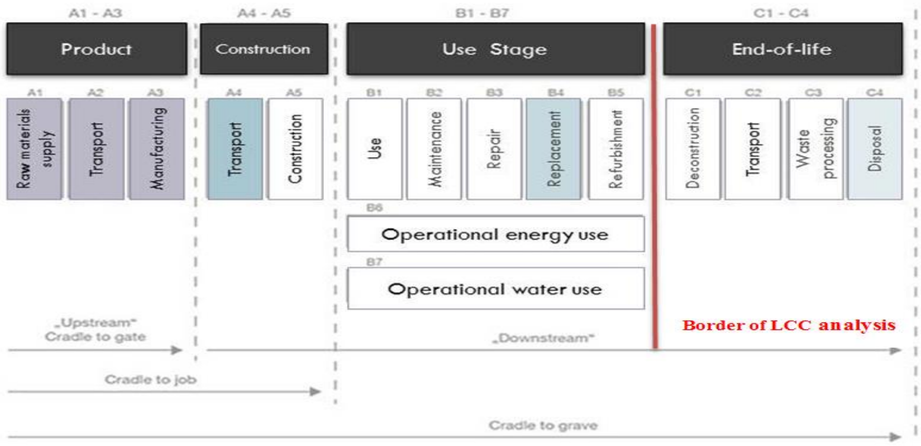



**Fig. 5 Life cycle scheme, source: EN 15 978.**

Within the LCC calculation method the equation 4 was used in order to determine the life cycle costs. The inflation factor – $I_f$ (equation 4), used for recalculating the costs for Net Present Values, is the deciding element regarding the implementation of the time factor.

$$LCC = IC + OC \times I_f + I \qquad (4)$$

Where IC – Investments costs, OC – operating costs (cost for space heating only), $I_f$ – inflation factor and I – Interest for loans (30 years).

$$I_f = \sum_1^n (1+r)^n = \frac{(1+r)x[(1+r)^n-1]}{r} \qquad (5)$$

Where n – years of lifecycle, n = 30 years is the period of the loan and r – change in energy price (prediction). Investment costs (IC) are the sum of the costs of building a new structure and the investor should bear in mind that the amount of investment costs affects the future amount of operating costs (OC), while the highest operating costs are usually caused by energy consumption. Median of the calculated costs from 5 potential construction companies was used for all evaluated alternatives for determining the investment costs. The addressed producers (construction companies) have the major share in the given market segment. This was also a reason why the investment cost calculation was considered representative.

An important element of the entire calculation should be, according to ALFARIS *et al.* (2017) and BADEA *et al.* (2014), the risk analysis encompassing the difficult predictability of the future costs (e.g. resulting from an increase in the energy costs etc.). This vague character can be considered in the final LCC calculation via carrying out the analysis of change sensitivity of the input calculation parameters using various scenarios of energy prices development or interest rate development. Table 2 presents the basic parameters of LCC sensitivity analyses for alternatives A1-A5. Information from the Eurostat database regarding the average value for last 10 years and correction in optimistic and pessimistic predictions were used for the recalculation.

**Tab. 2 Parameters of LCC sensitivity analyses for A1-A5 alternatives.**

| Prediction/ Factors | Average inflation rate | Interest rate of loan |
|---|---|---|
| Optimistic prediction | 1.25 % | 1.75 % |
| Realistic prediction* | 2.50 % | 3.00 % |
| Pessimistic prediction | 3.75 % | 4.25 % |

**Source: * Eurostat average value for last 10 years and correction in Optimistic/ Pessimistic prediction.**

## RESULTS AND DISCUSSION

Within the defined conditions for the RPB, Table 3 presents the results of the space heating energy consumption according to the standard STN 73 0540-2/Z1: 2016 Thermal performance of buildings and components, thermal protection of buildings.

**Tab. 3 Determining the space heating energy consumption according to the STN 73 0540-2/Z1: 2016.**

| Information | Alternative | | | | |
|---|---|---|---|---|---|
| | **A1** | **A2** | **A3** | **A4** | **A5** |
| Built volume $V_b$ [$m^3$] | 381.8 | 381.8 | 412.4 | 412.4 | 412.4 |
| Useful area $A_b$ [$m^2$] | 146 | 146 | 156 | 156 | 156 |
| Impact of thermal bridges ΔU | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Transmission heat loss $H_T$ [W/K] | 52.5 | 59.6 | 52.5 | 48 | 41 |
| Average heat-transfer coefficient [W/$m^2$K] | 0.155 | 0.169 | 0.155 | 0.129 | 0.109 |
| Ventilation heat loss $H_V$ | 45 | 45 | 45 | 45 | 45 |
| Total heat loss H ($H_{T\,+}$ $H_V$ ) | 97.5 | 104.6 | 97.5 | 93 | 87 |
| Passive solar gains $Q_S$ [kW/h] | 1143 | 1143 | 1143 | 1143 | 1143 |
| Free heat gains from people $Q_i$ [kW/h] | 2147 | 2147 | 2147 | 2147 | 2147 |
| Total $Q_{S\,+}$ $Q_i$ [kW/h] | 3290 | 3290 | 3290 | 3290 | 3290 |
| Space heating energy consumption $Q_h$ [kWh/ year] | 4879 | 5462 | 4879 | 4510 | 3935 |
| Space heating energy consump. [kWh/$m^2$ /year] ($Q_h$/$A_b$) | 34 | 37 | 31 | 29 | 25 |

The heat loss of the heating system, i.e. its efficiency, can be quantified according to the equation 2. The results are presented in Table 4. The energy consumption Q for alternatives A1-A5, which is a sum of the heat loss of the heating system and of the energy consumption $Q_h$ with the selected heating source – gas condensing boiler, is essential information in order to determine the operating costs for alternatives A1-A5 (Table 5). The current price list provided by the dominant gas distributor – SPP a.s. was used for determining the energy consumption.

**Tab. 4 Energy consumption for alternatives A1-A5 with gas condensing boiler.**

| Alternatives | Heat loss of the heating system $Q_l$ [kW/h year] | Heating energy consumption $Q_h$ [kW/h year] | Energy consumption Q [kW/h year] |
|---|---|---|---|
| A1 | 566 | 4879 | 5445 |
| A2 | 633 | 5462 | 6095 |
| A3 | 566 | 4879 | 5445 |
| A4 | 523 | 4510 | 5033 |
| A5 | 456 | 3935 | 4391 |

**Tab. 5 Quantification of operating cost for alterantives A1-A5.**

| Alternatives | Water Heat 4 persons €/year* | D2 Fee €/year | Price €/[kW/h] | Energy consumption [kW/h] | Operating costs €/year |
|---|---|---|---|---|---|
| A1 | 72.74 | 82.92 | 0.045 | 5445 | 400 |
| A2 | 72.74 | 82.92 | 0.045 | 6095 | 430 |
| A3 | 72.74 | 82.92 | 0.045 | 5445 | 400 |
| A4 | 72.74 | 82.92 | 0.045 | 5033 | 381 |
| A5 | 67.68 | 62.92 | 0.047 | 4391 | 337 |

**Source:** Price list by SPP 2019, Available: (https://www.spp.sk/sk/domacnosti/plyn/pre-domacnosti/dokumenty-na-stiahnutie/#ceny_dom), * 40 % (gas condensing boiler), 60 % (solar panels)

In order to quantify the investment costs for all alternatives, the median of calculated costs from 5 potential constructing companies was used. The building was divided into the following main construction units: foundation, ground floor, 1st floor, 1st floor ceiling, external walls, internal walls, roof, windows, doors and also item of final work. Table 6 and 7 provides information on the used components for the elements for alternatives A1-A2, A3-A5.

**Tab. 6 Quantification of investment cost and materials used for alternatives A1-A2.**

| Element | Area ($m^2$) | Price (€/$m^2$) | Components | Thickness (mm) | Alternative A1 | Alternative A2 |
|---|---|---|---|---|---|---|
| **External wall** | | | | 395, 465 | **15 773** | **15 280** |
| | 157 | 72 69 | Porotherm 38 T, YTONG YQ | 380, 450 | 10 219 | 9 824 |
| | | | Cement mortar | - | - | - |
| | 157 | 22 | Acrylate plaster outside | 10 | 3 333 | 3 274 |
| | 150 | 9 | Gypsum plaster skimming inside | 5 | 2 222 | 2 182 |
| **Internal wall** | 125 | 29 | | 105 | **3 704** | **3 714** |
| | | | Porotherm, YTONG | 100 | 1 202 | 1 207 |
| | | | Cement mortar and painting | | 1 381 | 1 384 |
| | | | Gypsum plaster skimming | 5 | 1 121 | 1 123 |
| **Foundation** | 92 | 140 | Concrete | 500 | **12 812** | **12 814** |
| | | | Insulation | | 3 837 | 3 838 |
| **Final work** | | | | | **37 264** | **38 208** |
| | - | - | Electro installation | - | 3 822 | 3 822 |
| | - | - | Water and waste installation | - | 1 077 | 1 077 |

| | | | | | |
|---|---|---|---|---|---|
| **Ground floor**<br>Kitchen, Living room | 56 | Laminated floor (living room) | 12 | 2 547 | 2 626 |
| | 82 | Concrete + floor heating system | 50 | 4 708 | 4 731 |
| | 82 | Expanded polystyrene + PE | 120 | 1500 | 1500 |
| | 26 | Ceramic floor tiles | | 2 229 | 2 298 |
| Bathroom, toilet | 9 | Ceramic wall tiles | | 1 155 | 1 185 |
| | | Ceramic floor tiles | | 1 433 | 1 477 |
| | | Bathroom accessories | | 2 884 | 2 983 |
| **1st floor**<br>bedrooms | 56 | Laminated floor | | 1 955 | 1 955 |
| | | Carpet (bedrooms) | | 1 092 | 1 092 |
| | | Concrete + floor heating system | 50 | 3 027 | 3 027 |
| Bathroom | 8 | Bathroom accessories | | 2 729 | 2 798 |
| | | Ceramic wall tiles | | 1 911 | 1 970 |
| | | Ceramic floor tiles | | 3 558 | 3 596 |
| | | Plasterboard | | 2 047 | 2 126 |
| **Roof** | | | 605 | **19 889** | **20 309** |
| | | Concrete roof (cladding) | 100 | 4 945 | 4 945 |
| | | Construction, insulation | 200+220 | 5 300 | 5 300 |
| | | Fermacell board | 12.5 | 2 967 | 3 093 |
| | | Wood Grill + mineral wool | 60 | 2 700 | 2 700 |
| | | Plasterboard ceiling, painting | 12.5 | 3 978 | 4 062 |
| **First floor ceiling** | 92 | | | **9 464** | **9 575** |
| | | Wood Grill from laths | 80 | 1 010 | 1 010 |
| | | Wood beams with mineral wool | 220 | 3 632 | 3 687 |
| | | Fermacell board | 12.5 | 990 | 990 |
| | | Wood Grill + mineral wool | 60 | 1 700 | 1 700 |
| | | Plasterboard ceiling, painting | 12.5 | 2 132 | 2 187 |
| **Windows** | | U-PVC frame, 3 glass | | **6 305** | **6 335** |
| **Interior doors** | | Laminated door | | **2 920** | **2 925** |
| **Exterior doors** | | Plastic door | | **2 433** | **2 489** |
| | | **Contribution margin (10%)** | | **12 261** | **12 392** |
| | | **Total costs (€)** | | **122,611** | **123,924** |

**Tab. 7 Quantification of Investment cost and Materials used for alternatives A3-A5.**

| Element | Area (m²) | Price (€/m²) | Components | Thickness (mm) | | | Alternative | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | A3 | A4 | A5 |
| **External wall** | 157 | | Timber frame construction | 296 | 336 | 436 | **17 122** | **18 165** | **19 510** |
| | | | Exterior plaster system | | | | 3 424 | 3 633 | 3 902 |
| | | | Wood Fibreboard insulation | 60 | 100 | 120 | 5 112 | 5 486 | 6 346 |
| | | | Fermacell board | | 12.5 | | 856 | 908 | 975 |
| | | | TFC with Mineral wool | | 140 | | 4 000 | 4 000 | 4 000 |
| | | | Installation gap | | 60 | | 589 | 998 | 1 146 |
| | | | Gypsum Fibreboard, paint | | 15 | | 3 140 | 3 140 | 3 140 |
| **Internal wall** | 125 | | | | 130 | | **3 294** | **3 628** | **3 627** |
| | | | Gypsum Fibreboard, paint | | 15 | | 888 | 988 | 988 |
| | | | timber frame construction with mineral wool | | 100 | | 1 547 | 1 714 | 1 713 |
| | | | Gypsum Fibreboard, paint | | 15 | | 859 | 926 | 925 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Foundation** | 92 | 140 | Concrete | 500 | **12 747** | **12 926** | **12 943** |
| | | | insulation | | 1 837 | 1 838 | 1 837 |
| **Final work** | | | | | **37 674** | **37 820** | **38 970** |
| | - | - | Electro installation | - | 3 422 | 3 422 | 3 422 |
| | - | - | Water and waste installation | - | 1 077 | 1 077 | 1 077 |
| **Ground floor** Kitchen, Living | 56 | | Laminated floor (living room) | 12 | 2 547 | 2 547 | 2 626 |
| room | 82 | | Concrete+ floor heating system | 50 | 4 708 | 4 731 | 4 731 |
| | 82 | | Expanded polystyrene + PE | 120 | 1500 | 1500 | 1500 |
| | 26 | | Ceramic floor tiles | | 2 229 | 2 298 | 2 298 |
| Bathroom, toilet | 9 | | Ceramic wall tiles | | 1 155 | 1 185 | 1 185 |
| | | | Ceramic floor tiles | | 1 433 | 1 477 | 1 477 |
| | | | Bathroom accessories | | 2 884 | 2 883 | 2 884 |
| **1st floor** bedrooms | 56 | | Laminated floor | | 1 955 | 1 955 | 1 955 |
| | | | Carpet (bedrooms) | | 1 092 | 1 091 | 1 092 |
| | | | Concrete + floor heating syst. | 50 | 3 027 | 3 084 | 3 084 |
| Bathroom | 8 | | Bathroom accessories | | 2 729 | 2 798 | 2 798 |
| | | | Ceramic wall tiles | | 1 911 | 1 970 | 1 970 |
| | | | Ceramic floor tiles | | 3 458 | 3 456 | 3 596 |
| | | | Plasterboard | | 2 547 | 2 576 | 2 647 |
| **Roof** | | | | 605 | **19 951** | **20 181** | **20 225** |
| | | | Concrete roof | 100 | 5 985 | 6 054 | 6 067 |
| | | | Construction, insulation | 200+220 | 4 976 | 5 090 | 5 112 |
| | | | Fermacell board | 12.5 | 2 000 | 2 000 | 2 000 |
| | | | Wood Grill + mineral wool | 60 | 3 000 | 3 000 | 3000 |
| | | | Plasterboard ceiling, painting | 12.5 | 3 990 | 4 036 | 4 045 |
| **First floor ceiling** | 92 | | | | **9 464** | **9 575** | **9 575** |
| | | | Wood Grill from laths | 80 | 1 010 | 1 010 | 1 010 |
| | | | Wood beams with mineral wool | 220 | 3 632 | 3 687 | 3 687 |
| | | | Fermacell board | 12.5 | 990 | 990 | 990 |
| | | | Wood Grill + mineral wool | 60 | 1 700 | 1 700 | 1 700 |
| | | | Plasterboard ceiling, painting | 12.5 | 2 132 | 2 187 | 2 187 |
| **Windows** | | | U-PVC frame, 3 glass | | **6 294** | **6 448** | **6 350** |
| **Interior doors** | | | Laminated door | | **2 919** | **2 933** | **2 944** |
| **Exterior doors** | | | Plastic door | | **2 477** | **2 531** | **2 511** |
| | | | **Contribution margin (10%)** | | **12 438** | **12 693** | **12 835** |
| | | | **Total costs (€)** | | **124,380** | **126,925** | **128,353** |

Regarding the results of quantifying the investments, it is important to highlight that the costs of individual components are different for each and every studied alternative. It is due to the fact that in the case of every studied alternative, a unified level for contribution margin of overhead cost and profit of 10% from the quantified items of costs was selected. The reason for selecting this approach was the individual approach of every potential constructor and keeping the confidential character of information about the contribution margin. This fact was mirrored in e.g. windows, where the ratio of costs of these components is at the level of 6,305 € (alternative A1, 5.1% of the overall investment) and 6,350 €

(alternative A5, 4.9% of the overall investment). The situation is similar also in the case of the doors, as well as other components. Although the components may be the same, provided by the same subcontractors, their pricing within the budget is usually different in case of every addressed construction company. It is caused by the various levels of contribution margin in cases of individual component prices. There are also differences in the item final works – Electro installation. Costs for alternatives A1-A2 are logically higher in terms of the required work.

If we wanted to express the ratio of individual elements for the studied alternatives, the highest costs were connected to the item final works. This item accounts for 30.4% (alternative A1) or 29.6% (alternative A5). The second most costly element regarding the studied alternatives were the components for the roof construction amounting to 16.2% (alternative A1) or 15.7% (alternative A5). These items are followed by the elements of the external walls (with 12.3% for alternative A2, up to 15.2% for alternative A5), as well as the foundation with a 10% ratio for the studied alternatives. It has to be mentioned that in case of all components (doors, windows, floors, bathroom fixtures), the standard (low cost) versions, which are usually included in the budgets of the construction companies for the complete house, were taken into consideration. If the customer required other components, it would certainly change the investment amount.

Figures 6 present the results of LCC analysis and its realistic, optimistic and pessimistic variant, which consider the difficult predictability of the future costs due to the increase in energy prices and changes in the interest rates (Table 5).

In the case of the realistic variant of energy price development, the inflation increase of 2.5% and average loan interest rate of 3% p.a. are predicted. Figure 6 presents the items investment costs (IC), interest of loan (I) and operating costs (OC). The lowest overall costs for a 30-year life cycle were quantified for the alternative of a silicate structure A1 at the level of 187,336 €. For the wood-based structure alternative with the type structure of the outside walls A5, the life cycle cost was quantified to 196,848 € representing a difference of 5%, with the overall difference of investment costs over 5,000 € in favour of the silicate structure. This difference could be eliminated by a targeted state support in the form of subsidies for wood-based structures and also for already built wood-based structures. Nevertheless, in spite of a marketing campaign and prepared legislative support, such subsidies have not been approved by the state so far. Nonetheless, it must be pointed out that with the operating costs at the level of specific heat requirement, the difference of 23% (4,200 €) was in favour of the wood-based structure.

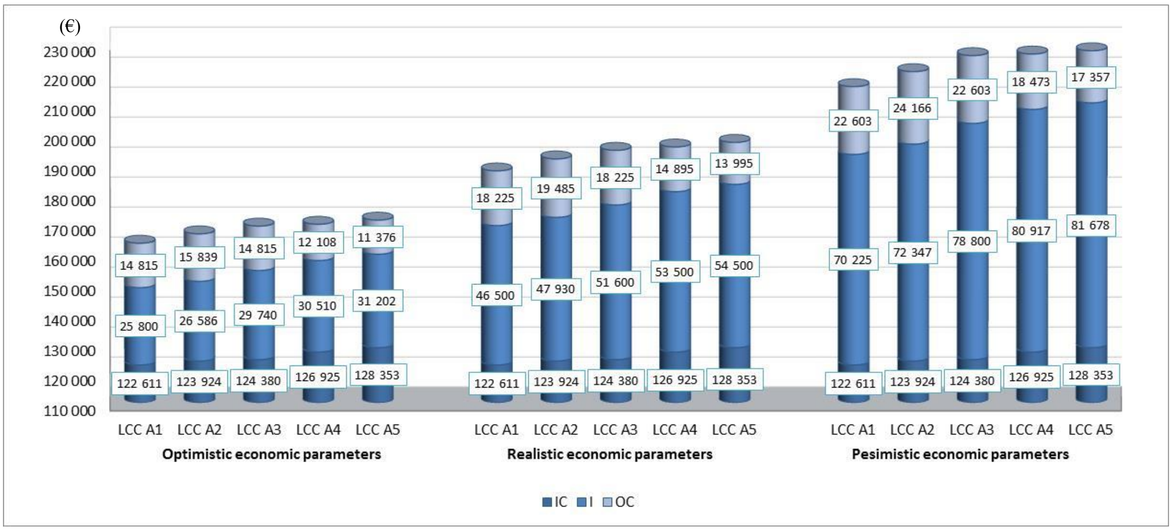



**Fig. 6 Results of LCC for A1-A5 alternatives for all economic parameters in €.**

For comparison, results of the optimistic prediction with the average inflation rate of 1.25% and interest rate of loan of 1.75% are provided (Figure 6). The differences in life cycle cost are smaller. For instance, with the alternatives A2 and A3, the difference is at the level of just 3.5% in favour of a silicate structure. However, the operating cost were quantified in favour of the wood-based structure (6.5% for alternative A3 and 23.2% for alternative A5). With the pessimistic prediction and average inflation rate of 3.75% and interest rate of loan of 4.25% are the differences more noticeable than in the case of the realistic or optimistic prediction. It is apparent that the amount of cost is affected by the selection of the structural materials, to a certain extent also by the construction company, as well as by the method of financing.

Since the investment cost are paid at the time of building, i.e. theoretically in the first year of the assessed period of the life cycle, the information about the difference in the repeated monthly cost covering the loan instalment and operating cost is relevant for the economic comparison. If we consider the life cycle cost per month (Figure 7) it is interesting to find out that the realistic prediction shows differences at the level of max. 23 €/month with the alternative A1 and A5, in the case of the pessimistic and optimistic prediction it is 30 €/month and 19 €/month, respectively. This difference could be eliminated in favour of wood-based structures by the financing conditions regarding the structure of own and borrowed capital in the ration of e.g. 50%:50%, i.e. using other ration than used in the study. However, also in such a context, the information about the amount of operating cost, being significantly lower in case of wood-based structure, would be important for the decision making process. The difference in the monthly cost would be 11.8 €/month for the realistic prediction, when comparing alternatives A5 (38.8 €/month) and A1 (50.6 €/month. With the pessimistic prediction, i.e. with a negative prediction of energy price development, the difference in the operating cost would be even higher (14.6 €/month), while with the optimistic prediction, the difference would be at the level of 9.6 €/month in favour of the wood-based structure.

However, the comparison of Life cycle cost could be unfavourable for the sector of wood-based structure also if the level of contribution margin and profit margin of the wood-based structure producers were higher than of the traditional construction companies. This can be a natural fact to a certain extent, mainly in the case when the overhead costs need to be allocated to a lower number of completed houses.

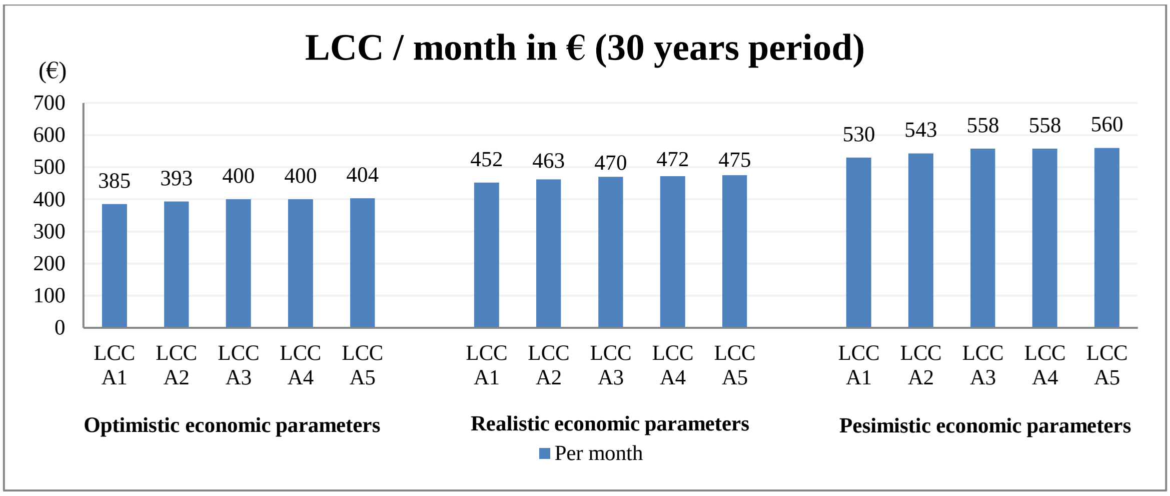



**Fig. 7 Results of A1-A5 for all economic parameters per month in €**

Results of LCC Analysis presented in this study for the Prototype Building – Family house in in the alternatives of silicate and wood-based structure cannot be compared with similar studies either in Slovakia or abroad. The reason is the high variability of the input components, as well as various parameters of the studied objects (e.g. the size of the building, purpose, location, materials used, economic parameters, etc.). There are many applications for the LCC in various fields, such as transport (DEBNÁR *et al.* 2016), energy sector (ISLAM *et al.* 2014, HU 2017), industrial production and civil engineering (BAEK, LEE 2013, BRADY, ABDELLATIF 2017). The LCC issue in the sector of civil engineering has been partially discussed in the studies of MORTENSEN *et al.* (2014), assessing the single family house in Denmark. Results of LCC analysis showed that the building refurbishment had a positive economic impact. In addition, NEROUTSOU and CROXFORD (2016) dealt with the issue of Life cycle costing of low energy housing refurbishment, with the conclusion that the investment into improving the thermal performance of the building had a positive impact on the assessment of LCC. NIEMILÄ *et al.* (2017) dealt with the cost-effectiveness of energy performance renovation measures in Finnish brick apartment buildings. Authors BADEA *et al.* (2014) presented the application of the mentioned method also in assessing the passive house, while the materials used for building the house have a positive impact on the overall operating cost in the long term regarding the assessed life cycle. Only few authors deal with combining the economic and ecological aspects of the life cycle of buildings. CHASTAS *et al.* (2017) is one of the authors, who proposed a conceptual combination of LCC and LCA into one assessing model. This model has not been applied practically so far, is has only been defined. The available studies mention more often the separate use of LCA. Life Cycle Assessment is a method comparing the environmental impact of products or services regarding their life cycle. According to LI and FROESE (2017) and LIN *et al.* (2017) the method takes into account the emissions into all components of the environment during the production, use and product disposal. The assessment considers also the processes of obtaining the raw materials, material and energy production, auxiliary processes or sub-processes. According to WU *et al. (2017),* VILCHES *et al.* (2017), WEILER *et al.* (2017) and SU *et al.* (2017) the LCA quantifies the potential impact of the product of service on the environment and is defined in the standards ISO 14040: 2006 and ISO 14044: 2006. The application of LCA in civil engineering is ever increasing and it has been repeatedly used for assessing new buildings. Examples can be found in the studies of MAOUDUS *et al.* (2016) and IQBAL *et al.* (2017). For effective elaboration of LCA studies, commercially available databases of processes, material and energy flows are used. It is one of the most important information tools of environmentally oriented product policy. MITTERPACH *et al.* (2018) present in their study the use of Life Cycle Impact Assessment of the designed wood based RPD while identifying the environmental impacts of individual house elements. Positive environmental impact of wood-based structures was presented also in the studies of ESTOKOVA *et al.* (2017), POTKÁNY *et al.* (2018) and BALASBANEH and MARSONO (2013).

## CONCLUSION

The presented findings confirm that a well-constructed wood-based structure can save costs in the operation phase although the investment cost is 4-5% higher when compared to the silicate building. The saving can reach 10 –15 €/month depending on the energy price development being the result of the material selection with a different value of heat transfer coefficient. Larger use floor area of 10 $m^2$ (7.5%) is one of the appreciable advantages of the wood-based structures associated with the RPB and higher investment is associated with this particular added value (Table 1). When considering other potential benefits of wood-based structures, eliminating possible risks and highlighting their ecological and environmental aspect regarding their environmental impact, the wood-based structures are a solution to move the building industry towards sustainability goals. This way the building industry will rank among the industries completely fulfilling the requirements of green business products.

The application of the Life Cycle Cost Analysis for the Reference Prototype Building – Family house using the alternatives of a silicate building and a wood-based structure with specifying the level of investment and operating cost for heating in the conditions of the Slovak Republic can be considered a contribution of the present study. The difference in the investment and operating cost could be eliminated by a targeted support from the state in the form of subsidies for wood-based structures, as well as by supporting the use of renewable energy sources. Nevertheless, it is also important that the producers of wood-based structures do not increase the contribution margin for overhead cost and profit margin artificially. Such approach will certainly create a potential for competitiveness and for increasing the market share of the wood-based structures on the Slovak market.

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