LCA analysis of Slovak residential building

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Abstract. Building industry is main contributor to greenhouse gas (GHG) emissions. According to goals of Paris agreement to achieve temperature rise below 2°C a year and then below 1,5°C a year, we need to find where are our biggest possibilities of improvement. Focus of this paper is on residential buildings built in Slovakia. With population growth also demand for apartments rises. With residential building development comes possible place for improvement. That is why main goal of this assessment is to analyse current state of our residential building fond using eToolLCD software and cradle to grave approach. Selected environmental impact of this analyse are, global warming potential (GWP), ozone depletion (OP), acidification potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP), abiotic depletion potential of elements (ADPE), abiotic depletion potential of fossil fuels (ADPF) and also use of primary energy resources (PENERT). Assessed residential buildings are first part of larger investigation in this sector.

1. Introduction
The building industry is leading industry in conjunction with negative environmental impacts and consumes large portion of resources. This sector is responsible for consuming up to 40% of the total energy consumption in EU, with a related 39% of carbon dioxide (CO₂) emissions if upstream power generation is included [1]. EU wants to comply Kyoto Protocol to the United Nations Framework Convention on Climate change (UNFCCC), which committed to reduce greenhouse gas emissions by at least 20% below 1990 levels, and by 30% in the event of an international agreement being reached [2]. Furthermore, long term goal is to reduce emission of greenhouse gasses even more till 2050 compare to levels from 1990, with aim to secure high energy efficient, decarbonized interstate building fond. One part to achieve these goals is by refurbish existing buildings and improve their energy efficiency [3]. Second part is built new buildings according to even higher criteria in terms of energy efficiency. But with this requirement rises also demand for focus on whole life cycle. This is supported by findings of Martin Röck at al. which came to conclusion that contribution of embodied GHG emissions increases up to and beyond ratio of 1:1 (embodied : operational) when 50 year life period is considered, for buildings that have adopted new energy performance standards for building operation [4]. Another review acknowledged the changing trend in percentage of caused GHG emission by each life cycle stage. One of conclusions was that, for low energy buildings, the other life cycle stages, than use stage, become more important, representing up to 65% of the building life cycle contribution [5]. With population growth, comes demand for new accommodation. Residential buildings show to be important area which to focus on, in relation to environmental impacts, with upcoming EU plan for new buildings to meet criteria of nearly zero energy buildings from 2020. Aim of this whole research is to examine residential building fond of Slovak republic and find possible areas for improvement. Subject of this paper is evaluation of new residential building located in Eastern Slovakia. This analysis focuses on several environmental impacts such as: global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), photochemical ozone creation potential (POCP), ozone depletion potential...
(ODP), abiotic depletion potential – elements (ADPE), abiotic depletion potential - fossil fuels (ADPF), and total use of non-renewable primary energy resources (PENRT). For modelling the life cycle impacts eToolLCD program was used. It uses the available database BRE IMPACT, version 4. To display the resulting data by the amount of environmental impacts for each category, the so-called inventory tables are used. Material information was gathered from project documentation and budget calculation. Energy consumption and water supply were gathered from technical report. Afterwards the collected data from documentation were one by one picked in the database of the program. If there was not the material with perfect match available the closest one was picked instead or parameters were slightly modified in program. If there was a possibility an EPD was added.

2. Methods and Research Process

Residential building located in Eastern Slovakia in Košice was chosen for this study. In time of conducting this analyse the building was still under construction.

2.1. LCA

Environmental life cycle analysis is a systematic tool used for assessing the environmental impacts associated with a specific product or service or building over their whole life cycle, including raw material extraction, manufacturing, stage of use, and end of life, disposal and potential of recycling [6][7]. This type of analysis is helping us to show compact picture about impacts related to the whole building. The requirements and procedure of implementation LCA analysis are defined in ISO14040 and ISO 14044 standard methods [8][8].

2.2. Goal and scope

The main objective of this study was analysis of new multi-story residential building with polyfunction. This building will be then part of the wider study sample consisting of existing buildings, new buildings and planned projects. System boundaries are set to cradle to grave. The functional unit utilized in this study was one square meter of gross floor area and estimated design life of 60 years.

2.3. Case study

Case study building is residential building located in Eastern Slovakia in Košice. In time of conducting this analyse the building was still under construction.

| Table 1. Building information. |
|-------------------------------|
| **Built-up area** | 1286.0 m² |
| **Usable floor area** | 4608.1 m² |
| - usable area for polyfunction | 177.4 m² |
| - usable area for apartments | 3600.6 m² |
| - usable area of apartment storage spaces | 249.7 m² |
| - usable area of apartment communication spaces | 536.4 m² |
| - usable area of technical background | 44.0 m² |
| **Terrace area** | 1162.1 m² |
| **Number of apartments** | 50 |
| **Number of polyfunctional spaces** | 2 |
| **Number of floors** | 7 |
2.3.1. Characterization of material and services used for reconstruction. Foundations of this building are designed as foundation feet mounted on piles. Piles are pyramid shape, made of reinforced concrete and prefabricated. Reinforced concrete foundation beams with a cross-section of height 700 mm and width 400 mm are designed around the perimeter of the building. Underground constructions are insulated with XPS polystyrene and protected with profiled foil. On the 1st above ground floor is designed monolithic reinforced concrete slab with variable thickness. Vertical load-bearing structures are designed as reinforced concrete monolithic multi-storey tree-field frames. Horizontal load-bearing structures are designed as continuous monolithic reinforced concrete slabs which will be mounted on mentioned frames. On them are floors isolated with EPS boards. Vertical communications in building are three-spoke reinforced concrete monolithic slab staircases with double-folded middle plate and edge plates. In building are also elevators, they are placed in monolithic reinforced concrete shafts. Building envelope consists of filler brick made of ceramic POROTHERM blocks. Envelope will be insulated with contact thermal insulation system based on mineral wool and skirting will be insulated with XPS polystyrene boards. Roof is designed as walk on terraces and impassable flat roofs with PVC waterproofing and EPS insulation boards. In living spaces with sanitary installation are made of suspended plasterboard ceiling. Windows frames and glass walls were made of aluminum profiles with isolating triple glazing. Entrance apartment door are designed as security doors class 2 installed in security frame. Interior doors are wooden installed in wooden frame. Exterior wall finish is made of silicone plaster, on terraces is floor made of frost-resistant concrete pavement. Step layer on staircases and hallows is made of glued anti-slip gress tiles. In apartments floor finish is made of ceramic tiles and laminated floor panels in rooms. Walls in interiors are lined with ceramic tiles in wet operation rooms and other walls will have gypsum plaster coating. Technical rooms and storage areas will be coated with lime-cement plaster.

**Figure 1.** Material composition sorted by mass (kg).
## Volume (m³)

| Material Description | Volume (m³) |
|----------------------|------------|
| Concrete (in-situ, RC35, excl. reinforcement) - concrete C 30/37 | 2849.662 |
| Brick, clay - POROTHERM bricks | 841.816 |
| Insulation (rigid sheet), EPS - ISOVER thermal insulation | 639.887 |
| Insulation (quilt), rock fibre -contact thermal insulation system | 586.264 |
| Concrete (in-situ, RC25, excl. reinforcement) - concrete C 25/30 | 548.5 |
| Block, concrete (aerated) | 290.688 |
| Floor (screed, floating), concrete (1:4 cement:sand) - leveling screed | 234.195 |
| Plaster, gypsum | 153.072 |
| Concrete (in-situ, GEN1, excl. reinforcement) - cement screed | 142.181 |
| Render, cement:lime (1:0:5:4) - stucco render | 40.902 |
| Reinforcement for RC, steel | 21.531 |
| General sheet (on framework), plasterboard | 20.466 |
| Insulation (rigid sheet), XPS (HFC blown) | 17.663 |
| General glazing, glass (toughened) | 16.889 |
| Floor finish (tiles), ceramic | 15.595 |
| Membrane (breather), polypropylene | 12.974 |
| Surface impregnation, sodium silicate solution | 12.434 |
| Render, cement:sand (1:4) | 11.214 |
| Block, concrete (dense) - acustic SILKA blocks | 10.314 |
| Roof covering (tiles, plain), concrete | 9.624 |
| Roof membrane (single ply), PVC | 5.378 |
| Window frame, aluminium (coated/protected) | 3.193 |
| Block, concrete (dense, cellular) - SILKA brick | 2.125 |
| Paint, emulsion | 1.668 |
| Vapour control layer, polypropylene | 0.383 |
| Door furniture/hardware, steel (coated/protected) | 0.085 |
| General sheet, Orientated strand board (OSB) | 0.075 |
| Roof cladding (inner lining, profiled), steel (coated/protected) | 0.004 |

### Figure 2. Material composition sorted by volume (m³).

#### 2.3.2. Building technical equipment.** Water for drinking, sanitary facilities and for the building fire safety system is provided by the public water supply. The heat source will be a hot water connection from district heating and a heat exchanger station in the building on the 1st floor. In the common corridors are designed electric radiant heating panels on the ceiling. Floor heating will be realized by Uponor - Tacker wet system. Exhaust radial fans with built-in non-return valve are designed for ventilation of sanitary facilities of toilets and bathroom. Ventilation of the ATS spaces is provided by a fan into the circular duct. The fan is used for air exhaust. ATS ventilation is vacuum based. Air supply to the room is solved at the floor through a fire grille. Same applies for OST space, distribution room. Engine room has in one case vacuum based ventilation in other overpressure ventilation. CO bunker has individual ventilation system which is not use during normal service. Electricity will be provided from commercial grid.**

#### 2.3.3. Operation of building.** Since building is still under construction, information about operation energy is obtained from the Project evaluation of energy performance of buildings. This part of building documentation has calculated values of energy demand for heating according to valid technical standards for climatic conditions – Košice. Results of calculation confirms that building meet the criteria for energy class A0.**
3. Results and discussion

Results of the LCA analysis of selected residential building, are presented in table 2. and also table 3. To be able to compare the results with different studies, two types of data tables were carried out. Table 2. shows environmental impact per m2 of usable floor area in estimated life span of 60 years. Table 3. shows another common measurement unit, environmental impact per m2 of usable floor area impact per year. These two sets of data will also make later use of data easier.

Table 2. Indicators characterizing environmental impacts for individual phases of building life per m2 of usable floor area.

| Characterized impacts per m2 usable floor area | GWP kg CO2eq | ODP kg CFC-11eq | AP kg SO2eq | EP kg (PO4)3- eq | POCP kg C2H4eq | ADP-E kg Sb eq | MJ |
|----------------------------------------------|--------------|-----------------|-----------|-----------------|----------------|----------------|----|
| Materials and construction                   | A1-A3 530    | 1.60E-05        | 2         | 0.48            | 0.32           | 9.30E-04       | 4800 |
|                                              | A4 43        | 2.60E-06        | 0.097     | 0.021           | 0.017          | 2.30E-07       | 580  |
|                                              | A5 0.16      | 1.10E-10        | 0.0019    | 0.0028          | 0.016          | 4.80E-10       | 0.014 |
| Use stage                                    | B1 -7.9      | 0               | 0         | 0               | 0              | 0              | 0   |
|                                              | B2 0         | 0               | 0         | 0               | 0              | 0              | 0   |
|                                              | B5 99        | 6.90E-06        | 0.83      | 0.31            | 0.094          | 1.30E-02       | 1500 |
|                                              | B6 4700      | 2.70E-06        | 0.48      | 0.11            | 0.063          | 5.30E-06       | 840  |
|                                              | B7 41        | 2.10E-06        | 0.2       | 0.047           | 0.012          | 9.60E-06       | 630  |
| End of life                                  | C4 3.1       | 2.5             | 0.019     | 0.041           | 0.00086        | 6.10E-04       | 0.37 |
| Total                                        | 2400         | 2.80E-04        | 3.6       | 1               | 1.8            | 2.60E-03       | 8300 |

Impact keys: over 40% (red); 31%-40% (blue); 21%-30% (orange); 10%-20% (yellow)

Product stage: A1 = Raw Material supply, A2 = Transport, A3 = Manufacturing; Construction stage: A4 = Transport, A5 = Construction; Use stage: B1 = Use, B2 = Maintenance, B5 = Refurbishment, B6 = Operational energy use, B7 = Operational water use; EoL stage: C4 = Disposal

Figure 3. Characterised relative impacts of three stages per square meter for fully enclosed floor area.

From figure 3 we can see that impact on GWP is greater in use stage. Almost 25% compared to almost 75%. This corresponds to findings from review of Röck M at al. Building categorized as new
standard, which corresponds to analysed building, show similar percentages for each of these stages [4]. Impacts causing ODP and AP are greater in material and construction stage. Impacts causing EP is almost similar for material and construction stage (49.9%) and use stage (46.2%). In this impact category is more visible also impact in end of life stage around 4%. For impact category POCP is more significant material and construction stage. Use stage has second largest impact in ADPE impact category with 56.6% impact. Material and construction stages are more significant for last assessed impact category ADPFF.

**Table 3.** Indicators characterizing environmental impacts for individual phases of building life per m² of usable floor area per year.

| Characterized impacts per m² usable floor area per year | GWP kg CO₂eq | ODP kg CFC-11eq | AP kg SO₂eq | EP kg (PO₄)₃eq | POCP kg C₃H₈eq | ADP-E kg Sb₂eq | ADP-FF MJ | MJ |
|--------------------------------------------------------|--------------|------------------|-------------|----------------|-----------------|----------------|----------|
| Materials and construction A1-A3                       | 8.8          | 2.60E-07         | 0.033       | 0.008          | 0.053           | 1.60E-05       | 79       |
| A4                                                     | 0.71         | 4.40E-08         | 0.0016      | 0.00035        | 0.00029         | 3.80E-09       | 9.6      |
| A5                                                     | 0.0027       | 1.80E-12         | 0.000032    | 0.000047       | 0.00026         | 8.00E-12       | 0.00024  |
| Use stage                                             |              |                  |             |                |                 |                |          |
| B1                                                     | -0.13        | 0                | 0           | 0              | 0               | 0              |          |
| B2                                                     | 0            | 0                | 0           | 0              | 0               | 0              |          |
| B5                                                     | 1.6          | 1.20E-07         | 0.014       | 0.0052         | 0.0016          | 2.00E-05       | 25       |
| B6                                                     | 0.289        | 4.50E-08         | 0.0079      | 0.0019         | 0.001           | 8.90E-08       | 14       |
| B7                                                     | 0.68         | 3.50E-08         | 0.0034      | 0.000079       | 0.0002          | 1.60E-07       | 11       |
| End of life C4                                         | 0.03         | 2.50E-11         | 0.00032     | 0.00068        | 0.000014        | 1.00E-10       | 0.0061   |
| Total                                                  | 39           | 5.00E-07         | 0.06        | 0.017          | 0.0086          | 3.60E-05       | 140      |

**Impact keys:** over 40% (red); 31%-40% (blue); 21%-30% (orange); 10%-20% (yellow)

Product stage: A1 = Raw Material supply, A2 = Transport, A3 = Manufacturing; Construction stage: A4 = Transport, A5 = Construction; Use stage: B1 = Use, B2 = Maintenance, B5 = Refurbishment, B6 = Operational energy use, B7 = Operational water use; EoL stage: C4 = Disposal

The residential building totally produces 2400 kg CO₂eq/m². Study of Monica Lavagna et al. [9][9] created sample of 24 representative EU dwellings with aim of creating a benchmark sample. Results for GWP impact varied from 34.4 - 99.9 kg CO₂eq/m²/year. Result of this study is 39 kg CO₂eq/m²/year. Study of Szalay Z on different types of building based on Hungarian building stock shows results from nearly 40 kg CO₂eq/m² for single family house to around 17 kg CO₂eq/m² for medium high multi-family building[10]. The ODP value of analysed building is 0.0000005 kg CFC-11eq/m²/year. This value is even lower than values mentioned in comparing study range 0.00000358 - 0.0000202kg CFC-11eq/m²/year[9]. Value in study by Szalay are approx. 0.000006 CFC-11eq m²/year for single family house and approx. 0.0000027 CFC-11eq m²/year for medium high multi-family building.[10] Value for AP is 0.06 kg SO₂eq m²/year. Values from Lavagna’s study are not comparable. Values from Szalay’s study are almost 0.10 kg SO₂eq m²/year for single family house and approx. 0.04 kg SO₂eq m²/year for medium high multi-family building.[10] Total value for EP is 0.017 kg (PO₄)₃eq m²/year this values is also not comparable with proposed benchmark sample. Values in study done by Szalay are approx.0.009 (PO₄)₃eq m²/year for single family house and approx. 0.0037(PO₄)₃eq m²/year for medium high multi-family building [10]. Value for POCP is 0.0086 kg C₃H₈eq m²/year and it also is not comparable with results from study by Lavagna et al. Study by Szalay shows results approx. 0.009 kg C₃H₈eq m²/year for single family house and approx. 0.003 kg C₃H₈eq m²/year for medium high multi-family building [10]. Value for ADP-E is 0.000036 kg Sb₂eq m²/year reported values in study of Monica Lavagna et al. range from 0.00186 – 0.00942 kg Sb₂eq m²/year [9]. Presented values are again much lower, more then 51 – times. Values from study of Szalay are missing for this impact. Value for ADP-FF which is 140 MJ/ m²/year is also not comparable and missing in other study.

**4. Conclusions**

In conclusion aim of this study was evaluation of residential building as one of the samples for further research. Analysed object belongs to category of new buildings, results shows that it doesn’t have larger
impact then sample of buildings from EU. This agrees with the EU's objective of reducing the environmental impact. Other conclusions are however that there is a need for standardization of methodologies. Even same impact categories don’t use the same impact or the impacts are similar but still not enough to be comparable.

5. References
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