Analysis of current situation in field of LCA.

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Abstract. With building industry and buildings large consumption of energy and environmental impact on planet, it is crucial to minimalize future consequences of our decisions. With help of LCA analysis, we can evaluate current situation and predict future impact of the design. This allows us to make better decisions in design stage of building process. There needs to be a lot of analysis to relevantly compare different types of buildings, in different environment and using different materials. This paper concentrates on current situation in this field of study, in global scale and with focus on Slovak republic.

1. Short history of the LCA method

We could say that first attempts in LCA problematics came in 1960s and early 1970s. These studies focused on energy consumption linked to manufacture of final product, especially packaging alternatives. Later on, the aspects examined expanded on material consumption, emissions and waste production. One of the first studies were financed by Coca Cola and their aim was to compare environmental impact of different types of soda packaging materials. Then in 70s, in Great Britain, Ian Bousted counted total consumed energy required for production of different packaging materials such as glass, plastic, steel, aluminium. He then consolidated the methodology and published a Handbook of Industrial Energy Analysis. The term REPA started to be recognized in USA in this context.

Between 1970 and 1990, the methodology of research did not have steady form. Standardization came gradually between 1990 and 2000. At the beginning, it was SETAC (Society of Environmental Toxicology and Chemistry), which, at a workshop, created a uniform methodology based on international agreement. Result of this effort was publishing the Guidelines for Life Cycle Assessment: A code of Practice in 1993. This codex became the base for creation of standard ISO 14 040 Environmental management: Life cycle assessment, principles and framework, from 1997. [1]

The interest about LCA has increased in new millennium. SATEC and UNEP (United Nations Environment Programme) published International Life Cycle partnership, known as Life Cycle Initiative. Aim of this initiative was to enhance support of LCA tools through enhancement of data and indicators and bring the whole analysis to wider awareness. Importance of this analytic approach grown also in European politics. In 2005 The European Platform on Life Cycle Assessment formed to support wider awareness in EU. In USA LCA was promoted by U.S. Environmental Protection Agency and simultaneously the environmental politics spread around the world. Unfortunately, methodologies started to differ. Besides LCA, LCC (Life Cycle Costing) and SLCA (Social Life Cycle Assessment) were formed. [2]
2. LCA (Life Cycle Assessment)
Structure of LCA analyses is guided by international standard ISO 14040. [3] For the processing, the commercial process and material flow databases are used. [3] The LCA is the main tool for environmental certification type III. [4] One of the main features and requirements for LCA are:

- Systematic and adequate dedication to aspects of production, from getting raw material to final waste disposal, so called “cradle to grave” system.
- Depth of detail and time frame can differ depending on definition of study aim and analysis scope.
- Scope, assumptions, description of data quality, methodology and output should be clear, transparent and well documented.
- Depending on LCA study used, it is necessary to have in mind even confidentiality of some information.
- This methodology should include scientific findings and improvements in modern technology.
- Specific requirements are included in analysis, so that it is possible to produce comparative claims that could be presented.
- LCA analysis could not be reduced to one total score or number, due to complexity of the whole methodology.

One unified method for LCA analysis doesn’t exist. Standardization is just guidance for processing of this analysis, but organizations should have opportunity to flexibly implement LCA for practical use in specific application and be able to fulfil users’ needs. (ISO 14040:19997(E))

3. Methodics of LCA
The frame structure consists of 4 major phases. Phases are often interdependent. Results of one inform about completion of other phases. (ISO 14040:19997(E)) [1] [5]

1. Definition of goal and scope – it defines, how big part of product life cycle, respectively building will be included in evaluation and what is evaluation’s purpose. It describes evaluation criteria and selected time horizon.
2. Inventory analysis phase – includes collection of material and energy flows within product system and mainly its interactions with environment, used amount of raw material and produced emissions to environment. It describes all significant processes and sub-flows of energy and materials.
3. Impact assessment – in this phase results of all studied impact categories indicators are evaluated.
4. Interpretation phase – in this phase critical review and analysis of data sensitivity should be made and the result of the analysis should be presented.

4. LCA variations

From the point of view of the studied time frame we recognize these types of LCA:

**From cradle-to-grave**
Full life cycle assessment from extraction of raw material (“cradle”), through stage of use to demolition, or so-called “grave.” In the case of buildings, it is from the extraction of raw material, through transport to the production, the building material production, transport to site, in-built, stage of use and possibly renovation stage to demolition.

**From cradle-to-gate**
This partial life cycle assessment begins with extraction of the raw material (“cradle”) and ends at production gate. It means it only focuses on evaluation until the product leaves factory. In case of building industry we consider the gate as the point from were stage of use begins. Stage of use, reconstruction and demolition are not included. Cradle-to-gate assessment is sometimes base for environmental product declarations (EPD) called business-to-business EPD.

**Cradle-to-cradle or Open Loop Production**
It is specific case of assessment, when, in the cycle, we also consider the stage of recycling after the end of building’s life. It is method used for minimizing impacts on environment by implementation of sustainable development, usage and demolition.

**Gate-to-gate**
In this type of analysis we focus just a part of the whole life cycle, just one chosen process. For example it focuses just on stage of use, or transport from factory to site. These gate-to-gate modules could be then assembled together and create wider assessment such as cradle-to-gate.

**Well-to-wheel**
It is another specific LCA used for analysing transport phases of life cycle. This type of analysis is often divided on stages called “well-to-station” or “well-to-tank” and “station-to-wheel”, or “tank-to-wheel”,

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**Figure 1.** Phases of LCA according to STN EN ISO 14040.
or “plug-to-wheel”. First stage, which includes entry materials or fuel productions, fuel supply or energy transport, is so called “upstream” phase. While the phase that deals with the actual operation of the vehicle is called “downstream”. Well-to-wheel analyses are normally used to assess total consumption of energy or efficiency of energy conversion. For emission impact of navy ships, airplanes and car emissions (including carbon footprint as well as fuel consumption typical for any of these types of transport), similar assessment are used. [3]

Also LCA divides into two types due to other criteria. It is attributional and consequential LCA. Again, it is focused on a time frame but also on the amount and type of data input. Attributional type of LCA focuses on impact linked to production and usage of the product (building), service or process in certain point in time (usually a near past). This data then interprets mostly facts. Amount of data is than limited. Consequential type of LCA analysis wants to identify environmental consequences due to certain decisions or planned changes in the system according to study. It orients on future and predicts future impact. Amount of data is not limited, because multiple variants should be examined, which are compared to achieve optimal decisions.

5. Studied impacts
It is possible to evaluate multiple impacts, some of them are:

**Global Warming Potential (GWP)** – Greenhouse gasses are warming up earth due to absorption of energy. This results in slowed release of energy to outer space. GWP was developed in order to compare this ability between different gasses, because it is not equal. More exactly, it measures how much energy is absorbed by 1kg of gas emissions in certain time compared to 1kg of CO\(_2\) emissions. Higher the GWP, higher the warming effect of certain gas on planet compared to CO\(_2\) in certain time. Usual estimated time is a 100 year. Unit is kg CO\(_2\) eq or CO\(_2\) equivalent. [6]

**Ozone Depletion Potential (ODP)** – It is ability of a chemical to deplete ozone layer. Unit set similarly to GWP. It has comparing character. It determinates ability of a certain chemical to deplete ozone layer compared with referential compound CFC-11 (CFCl\(_3\)). Different compounds are active in different layers of atmosphere and with different impacts in time. Unit is kg CFC-11 eq. [6]

**Acidification Potential (AP)** – It refers to rate of pH decrease in rain water and fog, which causes damage to ecosystem leading to, for example, drainage of nutrients from soil and increased dissolving of metals to soil. It is measured in weight equivalent to SO\(_2\). The highest impact is from burning fossil fuels, this causes release of SO\(_2\) and nitrogen, which are dissolved in condensed water in atmosphere and fall down as rain. Unit is kg SO\(_2\) eq. [6]

**Eutrophication Potential (EP)** – In general, eutrophication potential shows degree of nutrient enrichment in water or terrestrial environment, this leads to ecosystem damage from overreached enrichment and rate of quantity of phosphates equivalent. Unit is kg PO\(_4^{3-}\) eq. [6]

**Photochemical Ozone Creation (POCP)** – Nitrogen oxides contained in atmosphere (NOx, common polluting element) and organic dust particles (VOCs) could form ozone with presence of sunlight. Even if ozone in high atmosphere is crucial for protection against ultraviolet light (UV light), ozone in low levels of atmosphere causes different impacts, such as damage to plants and higher appearance of asthma and other respiratory difficulties. Potential of photochemical ozone creation (also known as summer smog) by compound emissions to atmosphere is measured in equivalent C\(_2\)H\(_4\) (kg C\(_2\)H\(_4\) eq). [6]

**Abiotic Depletion Potential – Elements (ADP - elements)** – It refers to depletion potential (or deficiency) natural resources (or elements), unused as source of energy, in earth, such as iron ore, aluminium, pressure metals and represents the final geological reserves and predicts amount of their depletion. It is measured in antimony equivalent. [6]
Abiotic Depletion Potential – Fossil fuels (ADP – fossil fuels) – It is similar to ADP for elements only ADP for fossil fuels counts rate of depletion potential for natural resources (elements) used for energy creation (fuels). Unit is MJ. [6]

Net use of fresh water (FW)) – It indicates overall net water consumption during whole building’s life cycle. Unit is m³ water.

Bre Eco Points – British rating system in environmental impact sector for buildings/products.

6. Tools and software
It was necessary to create databases of elements and materials to create LCA analysis and mainly to speed up and simplify whole process. This databases had to be updated according to production development, application of new and more effective ways of mining and extraction and many other factors. Databases should be locally divided, due to non-uniform production process methods and conditions in each country. For simplifying and effective LCA performing, the development of software tools for model processing. It is necessary to collect all information about used materials, their volumes, information about technical building equipment, operational information and other. In software those information are located and summarized. Databases then generate results. With this tools the whole process of analyse is simplified and more accessible. In short time from LCA development, many software tools were found. List of some of them is mentioned in table 1.

| Tool                                | Link                                                                 | Use     |
|-------------------------------------|----------------------------------------------------------------------|---------|
| Athena (Canada)                     | http://www.athenasmi.org/our-software-data/impact-estimator/        | Building|
| Arquimedes (Spain)                  | http://arquimedes.cype.es/                                          | Building|
| BEES (USA)                          | http://www.nist.gov/el/economics/BEESSoftware.cfm/                 | Building|
| Bilan Produit ADEME (France)        | http://www.base-impacts.ademe.fr/bilan-produit                     | General |
| Carbon Footprint (UK)               | https://www.carbonfootprint.com/                                   | General |
| COCON (France)                      | http://eosphere.fr/COCON-comparaison-solutions-constructives-        | Building|
|                                     | comfort.html                                                        |         |
| eToolLCD (Australia)                | http://etoolglobal.com/                                             | Building|
|                                     | http://www.eco-bat.ch/index.php?option=com_content&task=blogcategory&id=14&Itemid=30 | Building|
| Eco-bat (Switzerland)               | http://www.athenasmi.org/tools/ecoCalculator/                      | Building|
| EcoCalculator (Canada)              | http://www.athenasmi.org/tools/ecoCalculator/                      | Building|
| EcoEffect (Sweden)                  | http://www.ecoeffekt.se/                                            | Building|
| ECOSOFT (Austria)                   | http://www.ibo.at/en/ecosoft.htm                                   | Building|
| EIME (France)                       | http://codde.fr/en/our-software/eime-en/eime-presentation         | General |
| ELODIE (France)                     | http://www.elodie-cstb.fr/default.aspx                             | Building|
| envest 2 (UK)                       | http://envest2.bre.co.uk/                                          | Building|
| EQUER (France)                      | http://www.izuba.fr/logiciel/equer                                 | Building|
| GaBi (Germany)                      | http://www.gabi-software.com/                                      | General |
| GaBi-Build-IT (Germany)             | http://www.pe-international.com/sweden/services-solutions/green-    | Building|
|                                     | building/building-lca/                                             |         |
| GreenCalc+ (The Netherlands)        | http://www.greencalc.com/                                          | Building|
| Klimagassregnskap (Norway)          | http://www.klimagassregnskap.no/                                   | Building|
| LEGEP (Germany)                     | http://www.legep-software.de/                                      | Building|
| One Click LCA (Finland)             | http://www.oneclicklca.com/green-building-software/               | Building|
| OpenLCA (Germany)                   | http://www.openlca.org/                                            | General |
| SimaPro (The Netherlands)           | http://www.pre-sustainability.com/                                | General |
SBS (Germany)  

http://www.sbs-onlinetool.com/  

One from the two most common programs is SimaPro, with 25 year experience on market. But it is more oriented on product LCA. This program is licenced and contains a lot of databases. It uses standard ISO 14000 and generates his diagrams and other data according to it. Outputs are divided to three categories: emissions to atmosphere, emissions to water and emissions to soil. This emission dividing simplifies understanding of their impact effect. Demo licence is also available but only provides around 100 processes. Besides that it is still great tool for understanding and getting to know full functional programme.

Another tool is German GaBi. It is also more general but it contains specific building analyses. Is the most widely used tool on market and offers database of more than 8000 processes from different fields. Thinkstep Company revises data and methods used by this program every year. All entries are according to ISO 14040/44. Program is also licenced and offers 30 day trial of full version and demo version. [12]

Last but not least there is on-line tool eTool. It is open-use program founded in 2009. Reports from this program are accordance with ISO 14044 and EN 15978. It generates many impact factors. Besides already mentioned impacts there is also ability of recycling or radioactive potential. This is just part of many programs used for analyse processing.

7. Application example of LCA analysis from Czech Republic.

Very effective solutions were developed with rising demands on decreasing building energy performance. Materials with great thermo-technical features, new more effective systems of heating, wider use of renewable resources. Building energy performance decreased in stage of use phase, but this doesn’t mean, that environmental impact is necessarily lower with the use of some of these systems/materials. Production of thinner, more effective heat-insulating materials could be more energy demanding and ecologically worse than benefits from using it. In this case LCA is required. Different scenario comparison and evaluation of complex impact will help in decision making process. Only then, is possible to objectively evaluate energy and ecological impact. Example for this study is life cycle assessment of panel residential building type T06B from Czech Republic 1985, made by ČVUT.

| Characteristic                | unit  |                  |
|------------------------------|-------|------------------|
| Built-up area                | m²    | 409              |
| Usable floor area            | m²    | 1465             |
| balconies area              | m²    | 47.7             |
| Heated usable floor area     | m²    | 1065             |
| Internal gross area          | m²    | 5120             |
| Heated internal gross area   | m²    | 3480             |

Residential house has 14 apartments in total and around 45 inhabitants. The base is made of monolithic concrete slabs, on them prefabricated floor sills. Horizontal load bearing constructions are reinforced concrete panels with height of 2640-2660 mm and width of 140 mm. Vertical constructions are reinforced concrete ceiling panels 120 mm high and spanning 3460 mm. Staircase is double and prefabricated. Building envelope is made by large sandwich panels, inner wall is made of reinforced concrete 130 mm thick, then polystyrene 60 mm thick and finally outer wall made of reinforced concrete plate 70 mm thick. Roof is flat, single skin with waterproofing made of asphalt stripes. Windows are wooden and doubled. Non-load bearing walls are from plain concrete 80 mm thick. Floors are: 20 mm polystyrene, 35 mm spread concrete stepping layer with zero floor (this system is completed in loadbearing ceiling panel). Surface finishes are made by external washed-out teraco plaster, interior finish is by stucco plaster, cement milk (secondary rooms), lime pad and cement polished plaster. Building technical equipment: hot-water radiators, gas boiler, steel gas piping, PVC waste and water
piping. In early 90s, final energy consumption decreased (entrance energy to building about 5%). Gables were insulated with contact insulation 60 mm thick and covered with plastic facade plates in 2000.

**Energy performance decreasing scenarios**

**Scenario A** - thermal-technical reconstruction by insulation of remaining walls with 80 mm polystyrene, thermal-technical reconstruction of roof and related structures, leaving the structure and insulating with 120 mm thick foam polystyrene, attic insulating by 50 mm thick foam polystyrene, change of windows – plastic windows $U_w=1.4 \text{W/(m}^2\text{K)}$, boiler reconstruction (increasing efficiency of energy conversion to approx. 92%) and application of heating control by external temperature.

**Scenario B** - thermal-technical reconstruction by mineral fibre contact insulation 140 mm thick (current insulation will be removed), thermal-technical thick reconstruction of roof and related structures (removal of all layers and creating new structure with mineral fibre 200 mm thick, attic insulation with 50 mm thick mineral fibre), change of windows – wooden frames with panel polyurethane insulation layer and double glaze – $U_w=1.0 \text{W/(m}^2\text{K)}$, natural ventilation, boiler reconstruction (condensing boiler - increasing efficiency of energy conversion to approx. 102%) and application of heating control by external temperature - thermostatic.

**Scenario C** - thermal-technical reconstruction with use of passive building technology knowledge (it doesn’t necessarily mean decreasing heat consumption under 15 kWh/(m$^2$a)). Estimated change of object system boundaries, because it is optimal to unite not heated areas of first floor with heated areas to create compact shape and eliminate heat bridges. Thermal-technical reconstruction by mineral fibre contact insulation 220 mm thick, insulation of all details linked to construction by 50mm thick insulation, plinths insulation with 120mm thick extruded polystyrene, thermal-technical reconstruction of roof and related structures (removal of all layers and creating new structure with mineral fibre 350 mm thick, attic insulation with 50 mm thick mineral fibre), change of windows – wooden frames with panel polyurethane insulation layer and triple glaze (with plating and filling with noble gas) - $U_w=0.8 \text{W/(m}^2\text{K)}$, floor insulation on terrain (existing layer would be removed) by 100 mm mineral fibre plates, insulation of loggia panels and closing of loggia with pre-set glass wall, removing of current balconies and their replacement with completely separated construction, installation of mechanical ventilation system with recuperation, replacement of current boiler by biomass boiler, ½ heated water consumption covered from solar collectors and use of energy-saving appliances (estimated decrease of electric energy consumption by 50%).

**Table 3.** Panel building energy balance from realization to present. [7]

| Parameter                              | unit   | realization | 1992   | 2000   |
|----------------------------------------|--------|-------------|--------|--------|
| Heat requirement for heating           | kWh    | 178 800     | 171 650| 152 770|
| Countable heat requirement for heating | kWh/(m$^2$a) | 168       | 161    | 144    |
| Final consumption of energy            | kWh    | 324 980     | 308 730| 285 130|
| Countable final consumption of energy  | kWh/(m$^2$a) | 305       | 290    | 268    |
| Primal operation energy consumption    | kWh    | 552 479     | 513 369| 477 964|
| Countable primal operational energy consumption | kWh/(m$^2$a) | 519       | 482    | 449    |

**Table 4.** Panel building energy balance of proposed scenarios. [7]

| Parameter                              | unit   | Scenario A | Scenario B | Scenario C |
|----------------------------------------|--------|------------|------------|------------|
| Heat requirement for heating           | kWh    | 100 334    | 78 384     | 38 224     |
| Countable heat requirement for heating | kWh/(m$^2$a) | 94        | 74         | 36         |
| Final consumption of energy            | kWh    | 195 692    | 158 556    | 95 747     |
| Countable final consumption of energy  | kWh/(m$^2$a) | 184       | 149        | 90         |


When we look at table 5, we can see that inbuilt energy is higher in A scenario then in B scenario. It is caused by use of polystyrene as contact insulation. Production of this material is more energy consuming then production of mineral wool. There are visible differences between inbuilt emission CO$_2$ and SO$_2$. Despite the relatively similar volume changes in scenario A and B, even grater in case of B, the derogations are relatively small due to the choice of elements with smaller environmental impact during their life cycle.

### Table 5. Environmental impact quantifying of each scenarios – absolute values. [7]

| Parameter | unit | Original building | 2000 | 2004 |
|-----------|------|-------------------|------|------|
|           |      | Scenario A | Scenario B | Scenario C |
| Used material volume | m$^3$ | 1 499 | 1 513 | 1 623 | 1 726 | 1 939 |
| Used material weight | kg | 3 047 276 | 3 051 999 | 3 078 376 | 3 084 839 | 3 171 247 |
| Inbuilt energy consumption | GJ | 3 692 | 3 806 | 4 717 | 4 412 | 4 800 |
| Inbuilt CO$_2$ emissions | kg | 412 939 | 417 458 | 450 037 | 457 256 | 491 192 |
| Inbuild SO$_2$ emissions | kg | 1 700 | 1 733 | 1 946 | 1 896 | 2 051 |

Big impact difference in selected time is clear from this table after realization of each scenario. Case like this shows importance of analysis as important tool in decisions making process. Such a calculation should be one of the most important factors in the decision-making process for the protection of our environment and the pursuit of sustainable development.

### Table 6. Cumulated values of primal energy from non-renewable sources during life cycle. [7]

| Parameter | unit | 2000 | 2004 |
|-----------|------|------|------|
|           |      | Scenario A | Scenario B | Scenario C |
| Primal energy consumption from non-renewable sources | TJ | 39.4 | 98.5 | 88.8 | 52.1 |
| CO$_2$ emissions (operational + inbuilt) | t | 1 931 | 4 520 | 4 163 | 2 440 |
| SO$_2$ emissions (operational + inbuilt) | t | 7.7 | 21.3 | 21.3 | 15.7 |

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### 8. Conclusions

LCA analysis is relatively young research method but it should be more widespread to achieve sustainable development. In Slovakia, it is necessary to contribute more to the creation of databases and increase awareness about this method and to implement the LCA in the building design process, so that we can reach the more advanced countries were these projects are more used. Analysis and projects from Košice, Zvolen, Bratislava and SEVS (Central European University) are greatly contributing to popularization and spreading of LCA. Potential of this analysis is clearly visible in the above-mentioned Czech example.

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