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Carbon Footprint Associated with Construction Industry and Determination of its Theoretical Amount

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Abstract. The aim of this article is to analyse carbon footprint associated with construction industry, to identify its sources in the construction processes and to determine its theoretical amount in connection with its liquidation. In recent years, great emphasis has been put on the ecology issue and human impact on the environment, as the existence of global warming and the greenhouse effect due to human activity has been evident. The worst greenhouse gas affecting the mentioned situation is carbon dioxide. In this paper, the calculation of the carbon footprint is processed during the production phase of the house construction, in terms of material demand, in both low-energy and standard design. Furthermore, a calculation is made to calculate the carbon footprint equivalent. Subsequently, the economic demandingness of the investment in the construction of the above mentioned houses is evaluated, depending on the cost of material and the disposal of carbon dioxide. The obtained results imply that the amount of the carbon footprint, e.g. its environmental impact by the production of low-energy and standard houses in the construction phase is comparable, therefore the motivation for implementation of more ecological buildings is currently missing.

1. Introduction
Human activity in various sectors ranging from transportation, through food industry, to construction industry causes directly or indirectly emergence of greenhouse gases. National governments committed to limit them during the UN Climate Summit in Paris at the end of 2015 [1–2]. However, already in 2010, Regulation of the European Parliament and of the Council of Europe No. 305/2011 determined the uniform conditions for bringing construction products to the market. The seventh requirement was implemented in the regulation, i.e.: "The construction must be designed, constructed and demolished in such a way as to ensure sustainable use of natural resources". This includes recyclability, durability of constructions and use of environmentally friendly materials. One way of demonstrating compliance with this European Parliament Regulation is the Life Cycle Assessment Method. It is referred to as the LCA (Life Cycle Assessment) and the Environmental Product Declaration (EPD) is based on it. Part of the output of these studies is also determination of the carbon footprint index [2–3].

EPD is only at its beginning both in the construction industry and in many other fields in the Czech Republic. However, for example in Germany, Italy or Norway it has been already at a high level and hundreds of projects have been carried out in accordance with the EPD method. In order to determine a carbon footprint of a particular type of construction or a building in general, a lot of external data is required which is not directly dependent on each other. This indicator may not always be a priority for determining the level of environmental friendliness, material, product or construction [2–3].
Carbon footprint shows the building dependence on fossil fuels, both in the phase of its implementation and its operation. This information is, in the 21st century which is characterised by the fast growth in the effort to significantly reduce carbon footprint, crucial in economic, ecological and many others terms [2–3]. The term carbon footprint represents the sum of all greenhouse gases and becomes a clear indicator of the impact of human activity on the environment. It is an indirect indicator of energy, products and services consumption and the measure of the company operation impact on the environment (especially on climate changes). Carbon footprint can be understood and measured at several levels - national, urban, individual, corporate or product levels [4].

2. Literature review

Human existence, in most of its activities, produces a considerable amount of waste material and thus burdens the environment. The burden is represented by contamination of the bedrock environment, underground or surface water and greenhouse gas production. One of the most important greenhouse gases is carbon dioxide which production is also perceived as a carbon footprint. This concept is nowadays represented by the amount of CO₂ emissions emitted by human activities into the atmosphere. CO₂ growth is in particular a result of burning fossil fuels, agriculture, but also due to deforestation, ocean pollution and other land use changes [5–6]. Based on these negative impacts on the planet, companies should be guided by the philosophy of sustainability. Sustainability means that the economic, environmental and social factors of the company are assessed equally.

Air pollution by the production of greenhouse gases, which are dangerous for the functioning of both the ecosystems and human life, is one of the main issues of the society. In order to reduce carbon footprint emission in the course of time, several basic guidelines of ecological interest have to be observed [7]:

- Reduction of greenhouse gases emission,
- Re-usage of waste materials,
- Ecological architecture [8–9].

2.1 Construction industry as an energy efficient sector

Construction industry has had negative impact on the environment due to raw material extraction, through the building materials production and the construction of buildings itself to the production of waste and, last but not least, to the operation of the buildings themselves. This field is one of the most important for human existence, but at the moment the territory becomes built up, the area becomes dead and the landscape becomes fragmented. If one building is considered to be a unit of construction production, it is necessary to look at it not only from the implementation and operation phase perspective. Significant effects of life cycles of building materials arise already during raw material extraction, production, transport, maintenance and at the end of lifetime as well as by their demolition and disposal of waste. The LCA (Life Cycle Assessment Methodology), which aims at providing a detailed product description, including all its positive and negative environmental effects, is used to determine them. [3]

Construction industry field puts considerable demands and requirements on the recyclability of the materials used, environmental friendliness of the production and prevention of the release of toxic substances into the atmosphere. These demands also include minimizing the impact of construction activity on ecosystems, e.g. reducing pollution of water, air and soil as well as noise reduction. The main interests of management in the construction industry should include the effort to use building materials from different raw material sources efficiently and friendly, even with regard to the fact that they are non-renewable and scarce [8].

All over the world, the rule applies that if a residential building is implemented well, it does not need any additional resources to regulate the indoor climate. In the 1980s and 1990s, interest in energy-efficient constructions increased thanks to a group of German scientists who began investigating this issue in connection with global oil shocks and energy crisis [10].
The Energy Performance Certificate of buildings, determined by Decree 78/2013 Coll., establishes the limit amounts of passive, low energy and zero construction classes. Table 1 below shows the categorisation of constructions according to heat demand.

| Category               | Heat needed for heating |
|------------------------|-------------------------|
| Old construction       | app. double the amount of new constructions |
| Common new construction| 80 – 140 kW/m² per year |
| Low energy standard    | ≤50 kW/m² per year      |
| Passive standard       | ≥15 kW/m² per year      |
| Zero standard          | ≤ 5 kW/m² per year      |

New EU legislation came into force in 2010, requiring that, since 2020, new buildings in EU countries should be almost energy-zero, which means exclusively construction of passive houses. Reducing greenhouse gases emissions, protecting the environment and ensuring energy security in buildings are perceived as positive impact. In the Czech Republic, the response to this challenge is a Green Savings Programme, which is designed to support energy savings and the use of renewable energy sources. Higher investment costs for the acquisition are effectively used and after approximately 10 years of construction operation are paid back in comparison with the acquisition and operation of the ordinary construction [12].

Acquisition cost of the construction consists of direct and indirect costs. Direct costs consist of material, wage, machine and other direct costs. Indirect costs then constitute overhead costs and profit. The sum of all the costs of the material part of the construction is in fact included there. However, the cost of carbon dioxide emissions into the atmosphere, arising for example from the production of a mixture for joining masonry elements of the house, is missing. Not only the operational impact of the construction on the surroundings but also the pre-production impact plays its role.

When building energy-efficient constructions, the environmental burden rapidly decreases in the operational phase. Operational phase costs are generally around 48% and have the lowest impact on the environment in terms of environmental impact. This can easily be justified by the fact that the operational phase has the longest duration. Therefore, the question is not how to assess the impact of the construction in the operational phase but in the production phase. The influence of the Earth's climate by raw materials extraction, transportation and subsequent production of the individual elements of the construction used to be previously overlooked and sufficient attention was not paid to it. And if we subsequently set a graphical representation of the greenhouse gas production amount, then the largest proportion would apply to the production phase. This is due to raw material extraction, transportation and production of necessary materials. For this reason, the paper focuses on the emission of carbon dioxide equivalent during production of individual elements for a particular building [13].

2.2 Carbon footprint reduction

The commitment of the governments of the individual states of the world at the Paris summit has made carbon footprint reduction one of the main interests of companies nowadays. Reducing the CO₂ footprint is closely linked to cost reductions that are considered in terms of longer payback period. Companies, municipalities, and other entities can actively participate in the CO₂ MONITORING / REDUCTION programme launched in July 2015 and is the only one of its kind up to now. Its aim is to raise awareness of the climate protection issue. Several key steps to reduce emissions are listed below:

- Reducing the energy consumption of the company,
- Improving the logistics solution for the material transport,
- Reducing the number of business trips (replacement by videoconferencing);
• Exchange of service cars for electric cars or hybrid vehicles,
• Product Life Cycle knowledge (LCA);
• Reduction in the office paper consumption.

Main reasons for monitoring the amount of CO₂ production are as follows:

• Company carbon footprint information depends on the requirements of both domestic and foreign suppliers of service and products,
• Requested parent organization reporting,
• Development of the main objectives while reducing the impact on the climate,
• Reducing risks in relation with rising fossil energy prices,
• Focus on which parts of company activities have the greatest energy consumption and search for cost reduction options,
• Saving costs leads to significant competitiveness and trade growth.

At the time of passive houses, European regulations and greenhouse gas emission monitoring standards, emphasis is placed on the energy and environmental certification of buildings. To obtain it, detailed information about the building and, above all, the used materials and their properties is needed. Developers of new building materials are under great pressure due to monitoring resource sustainability and maximal reducing of the environmental footprint. It is not sufficient for materials to be just energy-efficient. Now they have to be nature-friendly. Monitoring of ecological requirements has begun, so the new criteria have been the energy consumption, CO₂ emissions and SO₂ emissions.

At the same time, it has been the need for their classification as renewable, recyclable or non-recyclable building materials [7]. In addition to the technical parameters of materials such as flexibility, strength, plasticity, it is also important to know the impact on the environment, on raw material and energy in production consumption.

2.3 Impact of carbon footprint on the price

If an object in the form of a house was broken down into individual structures and materials, it would be possible to determine the amount of carbon footprint of these parts. Unit prices can be easily identified, but it is not clear whether the price of the product is increased by its environmental burden.

In December 1997, the Kyoto Protocol came into force, which sets emission reductions for all countries in the world, to which the European Union was later included. In order for the EU to be able to fulfil this commitment, it has created a greenhouse gas emission market (EU ETS). In this market, the total quantity of greenhouse gases emitted has been determined in the form of so-called allowances (EUA). One allowance represents one tonne of greenhouse gas that can be emitted. Allowances are divided among polluters and allowances already used, are excluded from the market after use. The allocation of allowances is determined either by historical emission production or based on the operating efficiency. Every year, number of new allowances decreases and logically, the amount of emissions emitted decreases as well [14].

Over 11,000 facilities and power plants in 31 countries, as well as air transport in the EU countries take part in whole carbon dioxide trading system. The ETS covers around 45% of all EU production. The price of one allowance at the end of 2017 ranged at EUR 7.3/t of CO₂ and recently shows an increasing tendency. It seems to be the same in the future. Estimate for 2018 is EUR 11.5/t of CO₂, for 2019 it is EUR 13.56/t of CO₂ [15].

3. Methodology

The aim of this paper is to evaluate the influence of the production and implementation phase of the building on the environment in terms of CO₂ production and determination of the theoretical amount of the carbon dioxide footprint, so it is necessary to set the basic methodology of calculation. The object is assessed in two variants, in the low-energy and in the standard energy design. Calculation takes into account mainly the impact of the life cycle of the materials used for construction, which
represents raw material extraction, material production and transport. The building consists of a residential part, a terrace and a garage. The methodology only considers embedded constructions. The heating system is designed for a low-energy house using a heat pump with floor heating. A gas boiler is designed for a standard house. The amounts considered in the quantification of the CO₂ equivalent of the building work are taken from the Envimat.cz building materials catalogue. The object is divided into individual structures and their respective materials. These are considered as general without a manufacturer's assignment and detailed specification. Afterwards, the materials are assigned carbon dioxide emissions amounts to the specified unit of measurement. Then it is possible to determine the largest source of carbon dioxide from the building. The carbon footprint calculation itself is based on the summation of the respective amounts of individual materials and the comparison of the object in two variants. The item budget is needed for correct division of the object into the materials, determination of their price and the amount of their carbon footprint. The budget is based on project documentation. Furthermore, according to the emission allowance prices, the total CO₂ emission by realization of the house can be estimated.

Applied methodology consists in nine steps:

- Design of the house construction,
- Calculation of the heat transfer coefficient U for determining the class of the object,
- Penb determination in ENERGIE 2015 programme,
- Creating an item budget,
- Creating a limit list of materials for which a carbon footprint is known,
- Assigning the amount of CO₂ emission to material limit list,
- Summarizing CO₂ footprint for a given object,
- Calculating the carbon footprint of individual materials,
- Including the CO₂ price to the total cost of the house.

Carbon footprint is assigned to individual materials according to the Envimat catalogue. However, assigning CO₂ footprint to the selected heating system is problematic. Amounts used take into account the area of the object for which the heat pump is designed, its performance in terms of calorific amount, the demand for production and disposal of the materials needed, and the production of CO₂ cooling liquid. The total amount consists of the above mentioned parts and represents 2,570 kg of CO₂ equivalent when using the heat pump in the building. A similar calculation was carried out for a gas boiler and it is burdened by an amount of 455 kg of CO₂ equivalent when used as a heating system [16].

4. Results

The house project is designed for a four to five-member family as a one-storey bungalow with an added garage with a total area of 150 m². The calculation was done in two variants, in a low-energy and in a standard house design variant.

4.1 A low-energy house variant

The design and material solution of the house is satisfactory and it is therefore included in Penb A category. The budget of the house was created in the KROS plus program version 2016/1, which uses the CS URS price system. The total construction cost is CZK 3,230,417.08 (i.e. EUR 123,382,929.37 or $ 146,347,773.46). The item budget included all the important items for determining the approximate total cost. No sections of engineering networks, fixtures, or ancillary budget costs were considered. The central heating section is summed up separately. The air/water heat pump was chosen as a heating system for a low-energy house. The price is determined as an average of suppliers' prices from several price offers, namely CZK 200,000.00. Additionally, a material limit list is created because of allocation of the amount of the carbon footprint. The Envimat catalogue does not yet contain all the materials used. Therefore, it was necessary to remove all the items for which the carbon footprint cannot be determined from the determined material limit list. The total price of the
limit list is CZK 1,979,156.00, and the carbon footprint is determined for 81% of the materials used from the total budget. The adjusted limit list and the adjusted total cost of material demand for the building was then determined. Adjusted total cost of materials is CZK 1,562,824.00. After adding the heat pump price, the total price of the adjusted limit list is CZK 1,762,824.00.

Thermal insulation of the building has the largest share on the price and a heat pump has the second largest share on the price. With this heating system used, it is generally known that the expense of higher investment costs will only be paid back after several years of operation.

The price share of materials that were not included in the adjusted limit list is about CZK 416,332.00. The largest part is represented by a section of construction carpentry, which is amounted at CZK 182,349.00. Further they are also locksmith's constructions with an amount of CZK 45,951.00. Lintels and formwork also fall among important items not included.

The largest producer of CO₂ equivalent per kg of material is aluminium with an amount of 12.04 kg of CO₂ equivalent to produce 1 kg of aluminium. In the Envimat catalogue, it is marked as ECO-005. The second largest polluter is steel products with an amount of 4.47 kg of CO₂ equivalent to produce 1 kg of steel. This is understandable because the metal production includes energy-demanding mining, transport and processing. By contrast, the lowest amount of the carbon footprint has an aggregate. Concrete, which is generally the largest material demand of the building, has an average amount of 0.1 kg of CO₂ equivalent.

The total CO₂ production by material production for the low-energy house including the heat pump is about 71.83 tonnes of CO₂.

**Figure 1.** Percentage share of materials on the total carbon footprint for a low-energy house.

The graph in Figure 1 shows the percentage shares of the carbon footprint of individual materials obtained on the basis of the modified limit list for the construction of the low-energy building. The highest percentage is represented by concrete. This is due to the large amount of material used and its high bulk density. Thermal insulation and ceramic products also have a high share for the same reason as in the case of concrete. Although aluminium has the highest carbon footprint per unit of production
of this material, it does not have a large percentage share on the overall carbon footprint of the building because it has been used in small quantities.

For the valuation of carbon footprint, the average price of emission allowance for the year 2017 at CZK 144.00/t of CO$_2$ was used.

**Table 2.** Carbon footprint valuation for individual materials for the low-energy house.

| Material                                      | CO$_2$ emission tonnes | Total price of CO$_2$ CZK |
|-----------------------------------------------|------------------------|---------------------------|
| Concrete                                      | 17.70                  | 2,548.80                  |
| Thermal insulation (wadding and polystyrene)  | 10.60                  | 1,526.40                  |
| Ceramic blocks                                | 10.20                  | 1,468.80                  |
| Ceramic tiles and sanitation tiles            | 9.90                   | 1,425.60                  |
| Steel                                         | 6.10                   | 878.40                    |
| Plaster, mortar mixtures and screeds          | 3.20                   | 460.80                    |
| Aluminium                                     | 3.20                   | 460.80                    |
| Heat pump                                     | 2.60                   | 374.40                    |
| Wood                                          | 2.00                   | 288.00                    |
| Concrete boards                               | 1.80                   | 259.20                    |
| Oriented strand boards                        | 1.60                   | 230.40                    |
| Chimney                                       | 0.98                   | 141.12                    |
| Plasterboard structures                       | 0.69                   | 99.36                     |
| Textile                                       | 0.39                   | 56.16                     |
| Aggregate                                     | 0.49                   | 70.56                     |
| Hydro isolation                               | 0.19                   | 27.36                     |
| Others                                        | 0.19                   | 27.36                     |
| **Total**                                     | **71.83**              | **10,343.52**             |

The total cost of CO$_2$ production by the production of materials for a low-energy house in Class A in 2017 is CZK 10,344.00. Carbon footprint valuation for individual materials for the low-energy house can be seen from the Table 2. If this price is included in the total price of the adjusted limit list, the price of materials, including the environmental impact price, of CZK 1,773,168.00 can be determined.

**4.2 Standard house variant**

The construction and material solution of the building is satisfactory and was classified in the Penb C class. Compared to the previous class A, it differs in the structure of the perimeter wall.

The total cost of the construction was again determined using the KROS Plus system and was estimated at CZK 2,958,157.95. The heating system is not included in the price and was added separately.

Adjusted total cost of materials is CZK 1,414,605.00. To this price, it is necessary to add the cost of the gas boiler, which was chosen for the design of a standard house as a heating system. This system was included in the Penb calculation. The price was determined as the average of suppliers’ price offers from several price offers, namely at CZK 30,000.00. The total cost of the adjusted material limit list including gas boiler cost is determined at CZK 1,444,605.00.

The total CO$_2$ production due to material production for the standard design of the house including the gas boiler is approximately 64.95 tons of CO$_2$. 
Figure 2. Percentage share of materials on the total carbon footprint for a standard house.

The graph in Figure 2 shows that concrete has the highest carbon footprint. Ceramic blocks for vertical perimeter structures of the house represent the second largest load. The heating system has only 2% share on the total carbon footprint of the materials under consideration. As the minimum of thermal insulation was used in the standard house, its share was only 6.3%.

Table 3. Carbon footprint valuation for individual materials for the standard house.

| Material                                | CO₂ emission tonnes | Total price of CO₂ CZK |
|-----------------------------------------|---------------------|------------------------|
| Concrete                                | 17.72               | 2,551.68               |
| Ceramic blocks                          | 12.23               | 1,761.12               |
| Ceramic tiles and sanitary tiles        | 9.86                | 1,419.84               |
| Steel                                   | 6.10                | 878.40                 |
| Thermal insulation (wadding polystyrene)| 4.08                | 587.52                 |
| Plaster, mortar mixtures and screeds    | 3.23                | 465.12                 |
| Aluminium                               | 3.19                | 459.36                 |
| Wood                                    | 2.02                | 290.88                 |
| Concrete boards                         | 1.80                | 259.20                 |
| Oriented strand boards                  | 1.61                | 231.84                 |
| Chimney                                 | 0.98                | 141.12                 |
| Plasterboard structures                 | 0.69                | 99.36                  |
| Gas boiler                              | 0.46                | 66.24                  |
| Textile                                 | 0.39                | 56.16                  |
| Aggregate                               | 0.35                | 50.40                  |
The total cost of CO₂ emission by the production of materials for the standard design of a house in the Class C in 2017 is approximately CZK 9,353.00. Carbon footprint valuation for individual materials for the standard house can be seen in Table 3. If this price is included in the total price of the limit list, it is possible to calculate the price of materials including the cost of impact on the environment at the amount of CZK 1,453,958.00.

5. Discussion
The aim of the article was to calculate the amounts of carbon footprint for two variants of a house, in the low-energy and standard design. Approximate total building costs were also determined using the item budget. The carbon footprint valuation was made using emission allowances.

The calculation of the total price of the house shows that for a low-energy house the price is higher by CZK 442,259.00 without VAT. This price includes both assembly and material. The price of the chosen heating system was also included in the total price. The biggest price difference is in the proposed thermal insulation, which has a much higher purchase price for a low-energy variant, but prevents heat emission and in the operational phase there are far lower heating costs. The payback period for spent greater resources is approximately 12.5 years.

The largest amount of CO₂ emission was found out for concrete, due to the complexity of its production and transport. The large difference in CO₂ emission is in thermal insulation, heating system and ceramic blocks. This is due to the fact that classification of the house into the classes A or C depends precisely on these materials for the Energy performance certificate of buildings.

The chart in Figure 3 shows the price differences of materials with the calculated carbon footprint. The biggest price difference is for thermal insulation, namely CZK 186,764.00. In the low-energy house, a thermal insulation by 200 mm thick polystyrene boards in the perimeter wall and 300 mm of mineral wool in the roof structure layer was chosen. Each material has its amount and the market price is more or less directly proportional to its quality. The second biggest difference is CZK 170,308.00 for the heating system. The heat pump price is high because it has a high efficiency of heating and is one of the most promising sources of energy.

Similarly, the differences in the amount of carbon footprint are the highest for thermal insulation and heating system. Figure 3 below shows carbon footprint price amount differences. Due to the low disposal cost of 1 tonne of CO₂, the situation is not basically different from the classical material valuation.

6. Conclusion
Already in the pre-investment phase of a house project, it is very important to choose the most advantageous design of a house. It is generally known that the acquisition cost of a low energy house construction is far higher than the standard house design. But one of the main reasons why energy efficient buildings are being constructed is a quick return on investment, low operating costs and efficient use of renewable energy sources. Unfortunately, what is not included in the acquisition cost is the environmental impact of carbon dioxide emission during the production of materials. Therefore, the cost of disposing of the carbon footprint of each of the evaluated objects has also been compared in the article, see Table 4.
After assigning a carbon footprint to individual materials, an amount of 71.8 tonnes of CO₂ equivalent was determined for a low-energy house. For a standard house design, the amount was 65 tonnes of CO₂ equivalent. The difference of 6.8 tonnes is mainly represented by thermal insulation and heating system. Subsequently, the prices of emission allowances were assigned to the carbon footprint of the house, thus the price determined was CZK 10,344.00 (in terms of percentage on the final acquisition cost, it is 0.58 %) for a low-energy and CZK 9,353.00 (in terms of percentage on the final acquisition cost, it is 0.64 %) for a standard house. The cost of carbon dioxide emission is not high for the design of both variants of houses. This is due to the low price of emission allowances that were used for the valuation. Price of emission allowances is under 1% of percentage on the final acquisition cost for both variants. After an overall evaluation, the results have not been entirely satisfactory. Prices for the environmental burden by the construction of a low-energy or standard house are not high. This implies that even the investors with higher input capital have no motivation to build more environmentally friendly constructions. This is also related to the thinking of architects and designers who are not encouraged to make such designs. Even if the legal conditions were introduced through the carbon footprint emitted by the construction of one building, it would not have a major impact. Similarly designed studies should become an inseparable part of each building construction in the
future, and architects should address not only the economic but also ecological aspects of the designed construction.

If the society can quantify environmental impacts of the construction production, it can further work with these impacts, evaluate them, compare them, mitigate their effects, and develop more environment friendly production and processing technologies. Due to the advancement of the society, it is a duty to significantly reduce production of greenhouse gases and thus to preserve the environment in a condition corresponding to the appropriate living conditions. Therefore, the US announcement of withdrawal from the Paris Climate Agreement since 4 November 2019 may be referred to as regrettable.

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