Ecological Aspects of the Detached House Construction

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Abstract. The article deals with the ecological impacts during a detached house construction and looks for the optimal way of its financing. The aim of the article is to evaluate how much the house construction costs would increase in the case of the use of materials, which production generates smaller volume of negative emissions. The issue of the environment in relation to ecological construction has been widely discussed in recent years. The construction industry burdens the environment already by the production of building materials, extraction of raw materials, energy consumption, through designing activities and construction itself, to the phase of the building use and its eventual liquidation. There are six basic requirements for building materials used in construction, which are required for the quality environmentally friendly construction: the statics and stability of buildings must be provided, noise protection, fire safety, hygienic safety and reduced environmental impact must be met, buildings must provide safe use and well-being, and last but not least energy efficiency. Already in the structure construction phase, it is necessary to consider the appropriate selection of building materials, for which it is necessary to take into account ecological criteria. Appropriate selection of building materials results in a positive effect on the environment. When optimizing the total cost of building a detached house from an ecological point of view, the procedure consists in replacing the most cost-effective items in the construction budget by alternative materials with regard to ecology. When choosing alternative materials, maintaining the standard of the brick building and the aesthetic character of the house are taken into account. When comparing the budgets of both variants, it was found out that a detached house built using alternative, more environmentally friendly materials, resulted more expensive. However, the price difference is slight. Own housing can be financed in several ways. One option is to use your resources. However, this method is currently unrealistic for most people, and therefore they often choose the option of combining their resources with external sources. The most commonly used products for housing financing are building savings loans and mortgage loans. Another possibility is to use subsidy programmes for housing to finance the house, which are often focused on supporting ecological construction and housing.

1. Introduction

In today's hectic world, the investors often do not consider the consequences of construction production in connection with ecology. As a rule, the construction of a detached house itself produces negative emissions into the air, soil and water, which have adverse effects both on the environment and the human health.

The aim of the research described in the article was to determine the ecological impacts arising during the construction of a detached house and to establish the optimal way of its financing. The issue of the
impacts of the construction industry on the environment was carried out on the basis of finding out the emission values of construction materials listed in the Envimat catalogue. A construction budget was established after determining suitable alternative materials that produce a lower volume of negative emission components. Based on real specific variants of indicative calculations of mortgage loans provided by the banking company, the optimal possibility of the house construction financing was determined.

2. Scientific literature review
The environment represents everything that creates natural conditions for the existence of organisms, including humans, and is a prerequisite for their further development. Air, water, rocks, soil, organisms, ecosystems and energy form its main components. Mankind and the environmental components interact with each other. Thus, the environment forms a set of synthetic and natural components of the material world and the interaction of all the components that surround us and affect both the lives of humans, and all living organisms. [1]

The ecological footprint deals with human requirements for natural resources, which it measures along with the amount of waste. This quantity is expressed in area units, i.e. in global hectares. It determines the volume and rate of consumption of natural resources, namely meat, wood and other fuels, crops and waste production, which consists of municipal waste and carbon dioxide, which is released into the atmosphere. Consumption of these natural resources is compared with the ability of nature to absorb them, dispose of these wastes and also create new resources - biocapacity. The ecological footprint is usually determined as a single number. It can be set at the global, state or regional level, or for individuals or activities. [2]

The degree of impact of human activity on the environment (especially climate change) is characterized by a carbon footprint. The carbon footprint is a scale factor of the amount of greenhouse gas emissions created by certain activities or products. The results are given in CO2 equivalents. The amount of carbon footprint can be determined at the national, municipal, individual, company or product level [3]. The amount of greenhouse gas emissions that are produced during a certain activity, such as electricity generation and heating, fuel combustion or landfilling, is referred to as direct emissions. They are less difficult to determine, they can be more easily checked and possibly reduced. Indirect emissions represent the volume of greenhouse gas emissions that are produced during the entire life cycle of the products, i.e. from their production to eventual disposal. These are mainly emissions that are associated with the construction of houses, the production of building materials or production of cars. Their calculation depends on data from the product life cycle analysis. [4]

The environment is burdened, among other things, by the production of building materials, either directly (extraction of raw materials, emissions from mechanical technological processes in the form of crushing or grinding, emissions from thermal technological processes) or indirectly (transport - in case of higher amount of material, electricity consumption) during which production air pollution occurs. [5]

The environment can be interfered with permanently or temporarily as a result of construction activity. Permanent interference into the environment is by taking away agricultural land and by interfering with the landscape causing waste-production, which generates emissions, waste water and solid waste. Temporary interference with in the environment creates dust, construction machinery noise and traffic. [6]

The construction industry burdens the environment already from the production of building materials, extraction of raw materials, energy consumption and designing activities, construction itself (where, among other things, the surroundings of the construction site are influenced by noise and dust), to the phase of building use and its eventual liquidation [7]. There are six basic requirements for building
materials used in construction, which are required for quality construction: statics and stability of buildings must be provided, noise protection, fire safety and hygienic safety must be met, environmental impact reduced, the buildings must provide safe use and well-being, and last but not least, energy efficiency. [6]

Construction industry burdens the environment by different factors compared to other fields of industry and services. These factors may be the diverse nature of individual structures, different construction sites, dependence of construction on meteorological conditions - seasonal work, work in an unprotected workplace, lengthy production cycle, land is appropriated (mostly agricultural), building materials have considerable weight, which causes high demands on transport and mining. Emissions produced by means of transport can be reduced by choosing a suitable means of transport, reducing the weight of the structure and shortening the transport distance. Rail transport is rather unsuitable for the construction industry, as it does not lead directly to the construction site. It can only be used in exceptional cases. Reducing the weight of the structure must be considered already in the structure construction phase, namely by the appropriate selection of building materials, for which it is necessary to take into account ecological criteria. Appropriate selection of building materials also has an impact on the environment. When assessing m³ or kg, steel is the most demanding and wood is the least demanding material. When assessing the environmental burden in terms of material burden capacity determined in MPa units of strength, the most demanding is brick masonry, which is also high in emissions and land use. Traffic intensity is determined on the basis of fuel consumption in units of t/km. [6] Energy intensity of buildings is divided into:

- Investment energy - invested in the construction and demolition of the structure, energy of consumed materials;
- Operating energy - calculated per unit of usable area or enclosed space when using it. [6]

Housing burdens the environment with the energy and drinking water consumption, generation of municipal waste and the demands associated with the maintenance and operation of the building throughout its life. Energy consumption includes heating, hot water heating and other consumption, which consists of cooking, lighting, electrical appliances, etc. [6] Therefore, it is necessary to take this issue into account already in the project phase and to design a building that would affect the environment as little as possible. In particular, it should focus on the optimal way of heating, especially the use of recuperation. Furthermore, in the current climatic situation, the use of wastewater and rainwater collection for its further use is a topical issue. Water consumption is constantly increasing. In houses and residential houses in the Czech Republic, drinking water is used for all purposes. It results in a global decline in groundwater, so it is possible that the population may face water shortages in the future. Significant attention should be paid to surface and groundwater pollution.

When purchasing your housing, it is necessary to bear in mind in advance that this is a high investment. If people are in possession of enough of their own financial resources to acquire their housing, they are not at risk of indebtedness in the event of inability to repay. It is usually more common to finance one's housing with outside financial sources. They offer the possibility of acquiring housing almost immediately. Outside financial sources are mortgage loans, which are the most used type of outside funds, as well as loans from building savings, consumer loans and subsidies.

3. Comparison of selected structures and building materials in terms of their impact on ecology

In addition to the usual comparative parameters of building materials (such as prices, durability, etc.), there is currently an increasing emphasis on the environmental burden during their production [8]. Based on the price analysis of a type house, cost-significant items that can significantly affect the price of the construction work and at the same time can have an adverse effect on the environment, were chosen. These are mainly vertical and horizontal structures, surface treatments, floors and filling
installation, carpentry structures, dry construction structures, plumbing structures, layered roofing, joinery structures and locksmith structures.

The proposed materials were replaced by an alternative building material with similar technical properties but less negative effects on the environment. These two variants were then compared in terms of thermal and technical properties and environmental impacts during production. Finally, they were evaluated in terms of their purchase price. The information was obtained from the Envimat.cz materials catalogue, which gives values of the amount of the produced carbon footprint and sulphur dioxide, bulk density and bound energy.

The course of design and evaluation is shown on the possibility of changing the insulation system of the house [7]. In the original design, the thermal insulation of the perimeter ceramic masonry was proposed by a contact thermal insulation system made of EPS 70F polystyrene foam boards with a thickness of 150 mm (variant 1). For variant 2, a contact TF Profi thermal insulation system with mineral insulation was chosen from the same Isover manufacturer. These are insulation boards suitable for thermal insulation of the facades. They contain longitudinal basalt fibres. The boards are glued and anchored to a pre-prepared solid wall base.

The following Table 1 shows that thermal insulation of the building with mineral insulation is less energy-intensive in terms of environmental impact. Production emits a significantly lower volume of grey energy with a lower equivalent of CO2 and SO2 emissions. The comparison resulted in the conclusion that mineral insulation is a more environmentally friendly building material suitable for thermal insulation.

| Variant | 1 | 2 |
|----------|---|---|
| Item name | Polystyrene foam | Mineral insulation |
| Bound energy [MJ/kg] | 105.073 | 20.1923 |
| Bulk density [kg/m³] | 30 | 32 |
| Bound CO₂ emissions [kg CO₂ eqv./kg] | 4.2121 | 1.1331 |
| Bound SO₂ emissions [g SO₂ eqv./kg] | 14.900 | 8.3583 |

The current market undoubtedly offers insulation materials made from renewable sources. These include straw insulation, insulation of walls, floors and ceilings by cellulose fibres, board or blown wood-fibre wall insulation, insulation from technical hemp or sheep wool. When using these types of insulation, it is more appropriate to design the house as a wooden structure, not a brick one. Some of the above-mentioned materials do not enable application to a masonry base.

An important item, apart from the contact thermal insulation system, in this section is the installation of a ventilated wall facade by riveting on a steel grate. The cladding consists of fibre cement boards. Table 2 shows that the production of the basic components needed to make a ventilated facade is very energy intensive. If this facade area were also insulated with a contact thermal insulation system with mineral insulation, the production of CO2 and SO2 emissions would be significantly reduced and the value for the release of bound energy would also decrease.
Table 2. Parameters of basic elements of a ventilated facade. (Authors’ own work according to [9])

| Parameter          | Bound energy [MJ/kg] | Bulk density [kg/m³] | Bound CO₂ emissions [kg CO₂ eqv./kg] | Bound SO₂ emissions [g SO₂ eqv./kg] |
|--------------------|----------------------|----------------------|-------------------------------------|-------------------------------------|
| Fibre cement boards| 11.7707              | 1900                 | 1.0909                              | 2.4531                              |
| Steel              | 29.0668              | 7850                 | 2.0924                              | 8.2738                              |
| Total              | 40.8375              | 9750                 | 3.1833                              | 10.7269                             |

Figure 1. Comparison of energy components of basic elements of ventilated facade with mineral insulation. [Both source and own processing]

More structures and materials on the type house were replaced in this way. The total costs incurred in the construction of a detached house in the case of the use of materials that are less harmful to the environment are higher by CZK 126,087 (excluding VAT). This difference is calculated on the assumption that when looking for alternative materials, the standard of the brick structure and also the aesthetic character of the house shall be preserved. It is possible to use more environmentally friendly materials, however, these could reduce the service life of the house, have high maintenance requirements, and disrupt the aesthetics and appearance of the building.

Furthermore, a change in the method of heating was proposed. In the type house, heating by means of an electric boiler in combination with underfloor heating and a fireplace was planned. The reason was, at first glance, lower acquisition costs. Despite the higher acquisition costs, an investment in a heat pump was recommended, as the use of the subsidy may reduce the acquisition costs, so they may be approximately the same as the acquisition costs for an electric boiler (the price difference is minimal). The advantage is lower operating costs, where the investor significantly saves funds, and especially savings in electricity consumption and other emissions, which burden and have adverse impacts on the environment. [10]
4. Housing financing

Own housing can be financed in several ways. The first variant are own resources, i.e. savings. This way of financing housing is unrealistic for most people at present. Therefore, individual institutions provide various products that can be used to finance housing both independently and in combination with owner’s resources. The most common products of banking institutions are loans from building savings and mortgage loans. Another possibility is the combination of the above-mentioned financing options with drawing of subsidy programmes for housing.

Subsidy programmes in the Czech Republic are provided thanks to the State Investment Support Fund (hereinafter referred to as SFPI). It was established on 1 June 2020 by renaming it from the State Housing Development Fund. Its function remained the same, namely to support the development of housing in the Czech Republic. The aim of the fund is to co-create suitable preconditions for housing growth, motivation of entities operating on the housing market to take care of the housing stock, both at the national and regional level [11]. One of the state subsidies is the Programme for the young.

One of the most successful subsidy programmes today is New Green Savings Programme. It is mediated by the Ministry of the Environment and managed by the State Environmental Fund of the Czech Republic. The aim is to improve the condition of the environment, support the reduction of energy intensity of residential buildings, construction of low-energy houses, etc. It is used primarily for insulation of perimeter cladding, window replacement, green roof in the reconstruction of already existing houses and for the construction of low-energy new houses. There is also a programme for the introduction of new, greener energy sources [12]. This subsidy programme offers funding for solar thermal and photovoltaic systems, controlled ventilation systems (recuperation), replacement of electric heating with a heat pump system, replacement of local heaters, and, similarly to previous programmes, a subsidy for the use of heat from wastewater. [12]

The Ministry of the Environment together with the State Environmental Fund of the Czech Republic provide the Rainwater Subsidy Programme. This is a project of the National Environment Programme [13]. The aim of the Rainwater Subsidy Programme is to motivate citizens, especially owners and builders of houses and apartment houses, to effectively manage drinking water (taken from both surface and underground sources) and to provide a reduction in drinking water consumption. [14]

Budget costs were calculated for both variants, which are shown in Table 3:

| Variant                        | Budget costs   |
|--------------------------------|----------------|
| 1 – Standard design            | CZK 4,472,517  |
| 2 – More ecological design     | CZK 4,625,082  |

The following table compares mortgage loans for the original variant 1, representing the standard design of a detached house according to the designer. Variant 2 represents more environmentally friendly design. For each of the variants, the amounts of monthly instalments for the loan maturity period of 20 years and 30 years are stated.
Table 4. The amount of mortgage loan repayments for individual variants (Authors’ own work)

|                      | Repayment period 20 years | Repayment period 30 years |
|----------------------|---------------------------|---------------------------|
|                      | Variant 1 | Variant 2 | Variant 1 | Variant 2 |
| Annual interest rate | 2.05%      | 2.05%     | 2.04%      | 2.04%     |
| Annual Percentage Cost Rate | 2.20% | 2.20% | 2.19% | 2.19% |
| Fixation period      | 5 years   | 5 years   | 5 years   | 5 years   |
| Monthly instalments  | CZK 22,719 | CZK 23,481 | CZK 16,634 | CZK 17,192 |

It is clear, based on the above-stated values found, that higher budget costs also entail higher monthly instalments on any mortgage. However, it shows that the increase in costs for the more environmentally friendly variant was relatively small, and thus the monthly instalments increased by only hundreds of crowns per month.

5. Results and discussions
Investment costs were determined for a specific detached house. Firstly, two design variants were proposed. The first variant used standard building materials; the second variant used alternative materials with regard to ecology. The most expensive budget items were compared both in terms of investment costs and in terms of the burden on the environment during their extraction and production. Cost-significant items were vertical structures, horizontal structures, specifically ceilings, contact thermal insulation system, ventilated facade, joinery structures focusing on the comparison of hole fillings, dry construction structures, which dealt with prefabricated ceilings and curtain walls. Other costly items consisted of layered roofing, carpentry, plumbing and locksmith constructions, a flat roof and a steel pergola. When comparing the budgets of individual variants of house design, it was found that a house built on the assumption of the use of more environmentally friendly materials is by CZK 152,565 (including VAT) more expensive. It represents an increase by 3.3% compared to the planned budget of CZK 4,472,517. When searching for alternative materials, consideration was given to maintaining the standard of the brick building and the aesthetic character of the house. The possibility of financing the construction of a house was further proposed due to the fact that investing in housing can be demanding for many people. Mortgage loans were proposed for both variants of the house construction, with the amount of monthly annuity instalments with a loan maturity of 20 and 30 years.

The last part dealing with the environmental impact of the construction and the house operation was a comparison of acquisition and operating costs for heating and hot water heating, using a heat pump or electric boiler with a fireplace insert. Based on the calculations, it was found that the acquisition costs of the heat pump were significantly higher (compared to the cost of purchasing an electric boiler in combination with a fireplace insert), but its operation appears significantly more advantageous. The consumption of electricity and other emission components that have an impact on the environment were reduced at the same time. When taking advantage of subsidy programmes related to the purchase of a heat pump, the acquisition costs resulted almost the same as when purchasing an electric boiler. An investment in a heat pump was recommended for this reason.

6. Conclusions
The article focused on the ecological impacts during the construction of a detached house and its possible financing. The variant of the house design, assuming the use of building materials that are less burdensome for the environment during mining and production was recommended for the construction of the house. In percentage terms, the cost of materials with a lower environmental impact to the total cost of a house was only 3 percent. However, in some cases, ecological parameters would improve several times. In the designed type house, the individual parameters on average improved. The bound
energy in the proposed variant is lower by at least 80%, the bound CO₂ emissions by 70% and the bound SO₂ emissions by 50%. It is obvious that investing in a greener variant would pay off.

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