ENVIRONMENTAL PARAMETERS OF BUILDING MATERIALS AND STRUCTURES – DATA UNCERTAINTIES

Julie Hodková

CTU in Prague, Faculty of Civil Engineering, Department of Building Structures,Thákurova 7, 166 29 Prague 6, Czech Republic, julie.hodkova@fsv.cvut.cz

Summary

Nowadays, the term "Sustainable Building" already appears in many different areas of engineering. Evaluation of environmental performance of building materials, structures and buildings is one of the key areas enabling to influence the consumption of non-renewable energy sources and materials and production of emissions and waste from building industry still at the design stage of the building.

The article deals with the possible procedures for obtaining environmental parameters of building materials, especially embodied energy - PEI [MJ / kg] and embodied CO2 emissions - GWP [kg CO2,eq / kg], and explains their importance. An important part of this paper is the analysis of uncertainties and ambiguities in the data. It shows the differneces in the data from different environmental databeses and the resulting inaccuracies in final calculations. Examples show environmental evaluations of building materials and structures and differences in the results coming from using different databeses. It highlights the need to create a unified comprehensive database of building materials and structures, which will include both the environmental and technical parameters and will allow an accurate evaluation of the environmental quality of the designed structures. The article also mentions current creation of environmental catalogue of building structures typically used in Czech Republic. This catalogue should help current user to optimize his building not only economically (concerning material solutions), as it is usual today, but also environmentally, and all that during the design phase.

Keywords: material, environmental, GWP, PEI, embodied

1 Introduction to the topic

In developed countries it is estimated that the buildings during their entire existence consume by about 40% of the total energy production. This correspond to the emission of greenhouse gases (especially CO2, SO2, NOx, etc.), which is about 30% of the total. Moreover, the construction and built environment are producers of approximately 40% of man-made solid waste [1]. The problem of building industry and the actual building developement is not only energy consumption, emissions and solid waste, but also drawing on renewable and exclusively non-renewable sources of raw materials for the production of building materials and water consumption throughout the life cycle of buildings. Clear and specific quantification of these and other environmental criteria of the building can determine the level of damage to the environment. These data, along with others, allow you to create an optimized concept, which considers the sustainability of the building.

Energy consumption and emissions production during the life cycle of material (from raw material extraction and production of material to disposal) are two of the parameters used to select environmentally good solution. Wider utilization of materials with low values of embodied energy (PEI) and embodied CO2 emissions (the GWP) indicates better environmental quality.

Assuming the energy consumption and CO2 emissions, it is true that for most of the existing buildings operational phase would prevail over construction phase and it would seem that PEI and GWP are minor matters. But today, when more and more low energy or passive houses are built, the difference between these two phases is decreacing, primary energy consumption for construction and related emissions gain greater importance. Time evolution of the ratio between embodied and operational energy of an object is shown in figure 1.

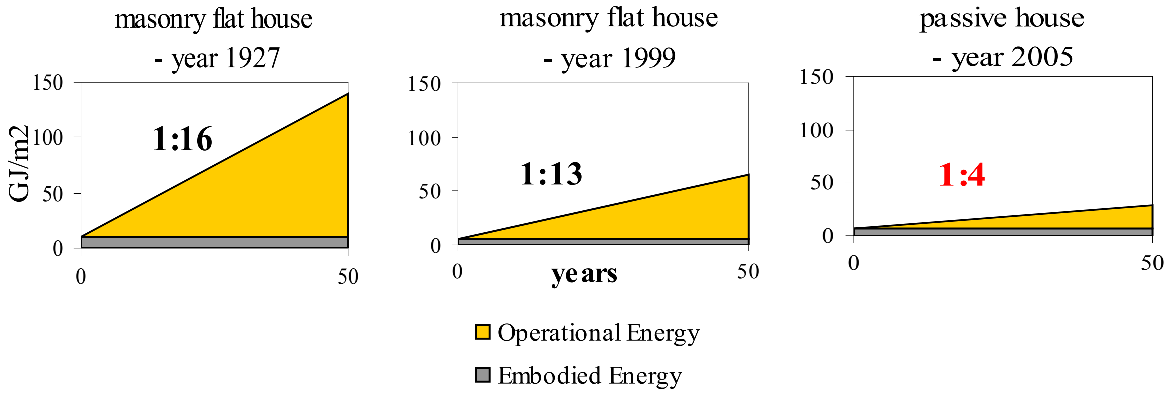


Fig. 1 The ratio between embodied and operational energy consumption [2]

Therefore creating a method for assessing the environmental quality of building materials and constructions is gaining importance. If the user can easily compare the environmental quality of several variants of the proposed structures, it could motivate him to choose the "greener" and could thus reduce the impact of construction on the environment.

In order to develop such a reliable method, it is necessary to have good data, whose deficiency is now a major problem.

2 Current development in the field

2.1 Existing tools

Currently, there are already various complex methodologies for assessing environmental, but also the social and economical quality of buildings. One of the basic methodologies is the life cycle assessement - LCA. This methodology is described in a set of standards ISO 14040-49 [3] and is applicable to any product of human activity. Furthermore, there are various assessment tools, evaluating the impact of construction on the environment. These can be divided into several groups:

- complex, covering over 100 criteria assessing the building and its surroundings, both in terms of environmental, social and economical view (e.g. LEED, SBTool, BREEAM, HQE, etc.)
- aimed at evaluating the building from a specific point of view - such as building energy performance, Life Cycle Cost, etc. (e.g. Athena, Energy Plus, Energy 10, etc.)

- examining only certain criteria such as environmental properties of materials and structures – e.g. the value of embodied energy and embodied CO2 emissions (e.g. SimaPro, Ecosoft, BEES, EPD, GEMIS etc.)

2.2 Existing databases

Each of the previous methodologies include evaluation of environmental characteristics (PEI, GWP, etc.) of used materials, whether as one of the main or marginal criteria. To quantify them it is necessary to use available environmental data, which can be found in material databases such as:

- Ecoinvent – Swiss Centre for Life Cycle Inventories - world's leading database with consistent and transparent, up-to-date Life Cycle Inventory (LCI) data. With more than 4'000 LCI datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment.
- IBO Baustoffdatenbank – IBO (Austrian Institute for Healthy and Ecological Building) – data of Global warming potential (GWP), acidification potential (AP), Primary Energy Content - renewable and non-renewable (PEI e, PEI ne), Production of photooxidants (POCP), Eutrophication (EP).
- ICE database (Inventory of Carbon and Energy) - Department of Mechanical Engineering, University of Bath - embodied energy (PEI) and carbon (GWP) of a large number of building materials.
- Documentation SIA D 123 – SIA (Swiss Society of Engineers and Architects) - data of Global warming potential (GWP), acidification potential (AP), Primary Energy Content - renewable and non-renewable (PEI e, PEI ne) etc.
- INIES - French database of reference on environmental and health characteristics of building materials and products.
- EPD (Environmental product declaration) - environmental performance of products

3 Uncertainties of the data

Each of the above-mentioned databases used to determine the necessary data with their own methods. Because of the number of available databases it can be easily inferred that final evaluations will be substantially different from one another as well as the data are. Differences are further described in the following articles.

The most important parameter that should be determinated for further work with the data is the value of embodied energy (PEI), i.e. the primary energy consumed during the life cycle of materials. In order to achieve a precision and certainty of data, it is necessary to establish system boundaries for the evaluation. The calculations of PEI usually involve life-cycle phases from extraction of raw materials to manufacture of the material, i.e. "Craddle to Gate". There are also other possible system boundaries- "Craddle to Site“ (i.e. " Craddle to Gate "+ transport to the site) and „Craddle to Grave“(i.e. whole life cycle of material, including its installation, operation and disposal).

After the values of PEI are obtained, it is possible through various conversion factors to calculate GWP, AP (embodied emissions SO2) etc. which are difficult to calculate individually. The conversion factor is often determined from a typical composition of the fuel in a particular factory or in the industrial area. It is always best to use the same conversion factor for the entire data set.

3.1 Data from manufacturers

The most accurate databases get the necessary data directly from the manufacturers of the material. It is necessary to have access to detailed energy consumption of the individual processes associated with the production of the material, i.e:

- Energy extraction and preparation of raw materials
- Energy needed to manufacture and supply of ingredients (i.e. PEI of additives)
- Energy to produce the material itself (mixing of ingredients, burning, etc.)
- Etc.

If it were possible that any producer could simply fill in the specific composition of the product and thus obtain the resulting values of environmental parameters, it would achieve the high reliability and accuracy of data.

3.2 Data from secondary sources

There are databases based on the collection of already existing data. It is certain that the previous method is more accurate and reliable, but on the other hand, it can be very complicated and sometimes nearly impossible. It depends on the quality of data that can be obtained just from the manufacturers, and these are often unavailable or inadequate.

The necessary data can be drawn from secondary sources in the public sphere, including newspaper articles, LCA assessments, books, conference proceedings, etc. Whith such a collection of data we encounter many pitfalls. The biggest in particular is that the evaluation system boundaries are not always clearly defined, so data with different system boundaries (e.g. "Craddle's Gate" and "Craddle's Grave") can be put at the same level. It is true that for certain materials (especially those who have a high value of PEI and high density – e.g. steel), the differences are minimal. Otherwise (e.g. sand, aggregates), the difference is significant. Therefore, there is a need for each material in the database to clearly define the system boundary, so that users realize the differences that emerge e.g. in the transport of the material.

3.2.1 Methodology of data collection from secondary sources

To achieve the greatest possible consistency and accuracy of data obtained from secondary sources, it is necessary to observe certain rules:

- Data obtained in accordance with approved methodologies / standards
- Identical system boundaries - such as "Craddle to gate"
- Preferably the same origin of data, if not, then the data need to be adapted
- Age of data sources - a modern take precedence
- GWP – ideally get from a detailed LCA, if unavailable, than need to be calculated using conversion factors of the typical composition of fuel in the area.

3.2.2 Differences in data over time

The following figure 2 displays data from different manufacturers over time, that shows differences in the development of technology, etc., but also in the methodologies used [7].

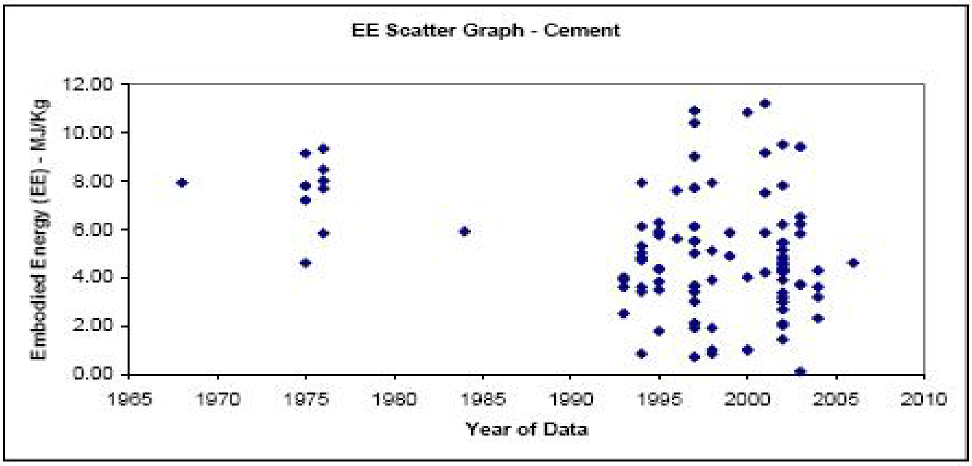


Fig. 2 Material scatter graph of embodied energy of cement
"Uncertainty is unfortunately a part of embodied energy and carbon analysis and even the most reliable data carries a natural level of uncertainty." [7]

3.3 Transport of materials

Transport of materials from production to the site should form a separate part of the environmental assessment. If you consider only a kind of average value – i.e. the methodology used by the system boundaries "Craddle to site“ (for example it would be envisaged that the concreting plant is always 50 km far from the site), the resulting values would again take another uncertainties. Therefore, each user should be able to enter transport distances into the calculation and thus obtain more accurate data.

Conversion of various energy consumed for transport (oil, gas, etc.) to CO2 emissions will be made by conversion factors.

4 Differences of environmental parameters in vrious databases

At the following table 1 you can see the differences in the parameters of embodied energy and CO2 emissions of selected materials from two different databases - IBO [6] and ICE [7].

Table 1 shows that most of the values are not very different. Although, the difference in resulting values may be significant when the weight of the materials can be thousands of kilograms. But parameters of some materials varies considerably.

Tab. 1 Differences in environmental parameters of building materials from two different databases IBO and ICE

Environmental parametres of building materials	PEI [MJ/kg]		GWP [kg CO2,eq/kg]	
	Database			
Materiál	**IBO**	**ICE**	**IBO**	**ICE**
Aluminium	124,000	155,000	8,910	8,240
Concrete C25/30	0,690	1,080	0,100	0,153
Cement	4,490	4,600	0,770	0,830
Brick	2,490	3,000	0,180	0,220
Timber general	1,890	8,500	-1,409	0,460
Woodwool	4,400	10,800	-0,140	0,490
Clay	3,070	0,450	-0,050	0,220
Aggregate	0,080	0,100	0,004	0,005
MDF	11,900	11,000	-1,040	0,590
Mineral wool	23,300	16,600	1,640	1,200
Steel	22,700	24,400	0,935	1,770
Sand	0,330	0,100	0,020	0,005
Polystyren	102,000	88,600	3,450	2,500
Glasswool	49,800	28,000	2,260	1,350
Gypsum plaster	2,560	1,800	0,130	0,120

At the following figure 3 and figure 4 there is an example showing differences in the assessment of wooden building using a total weight of wood about 35000 kg.

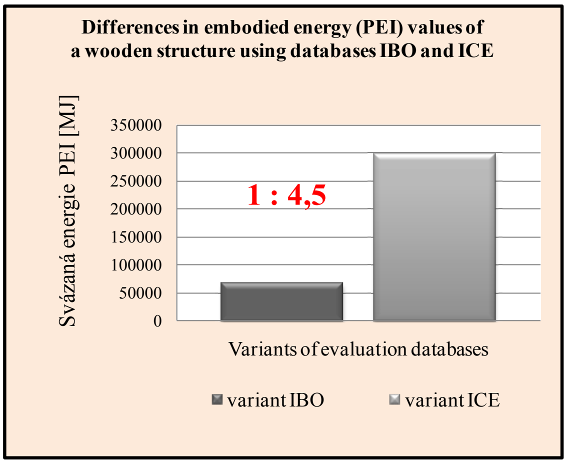


Fig. 3 Differences in embodied energy of wooden structure of a building evaluated with IBO or ICE database

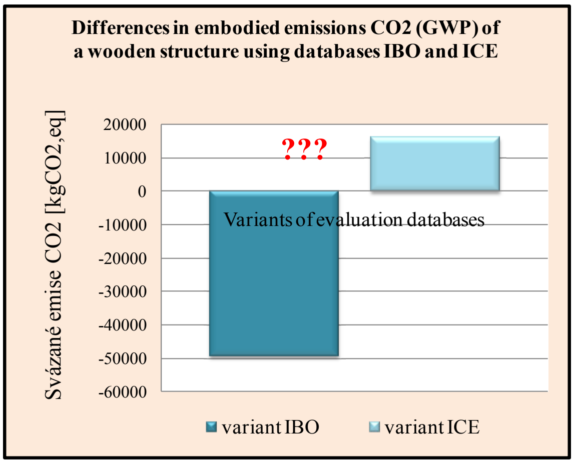
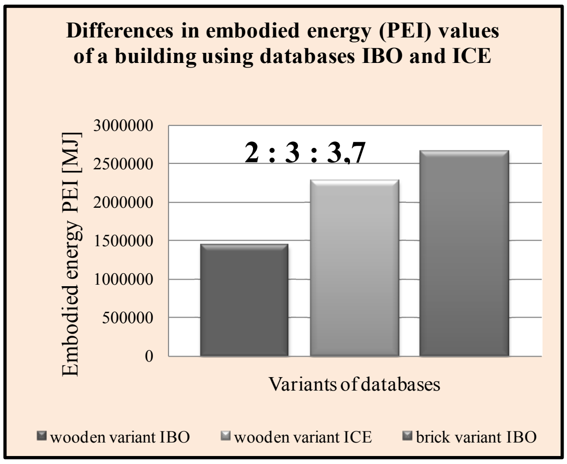


Fig. 4 Differences in embodied CO2 emissions of wooden structure of a building evaluated with IBO or ICE database

The following two figures 5 and 6 show the environmental evaluation of different solutions of one building. It is clear that using various databases one can achieve approximately the same environmental quality of brick and wooden building, which could be then very misleading.



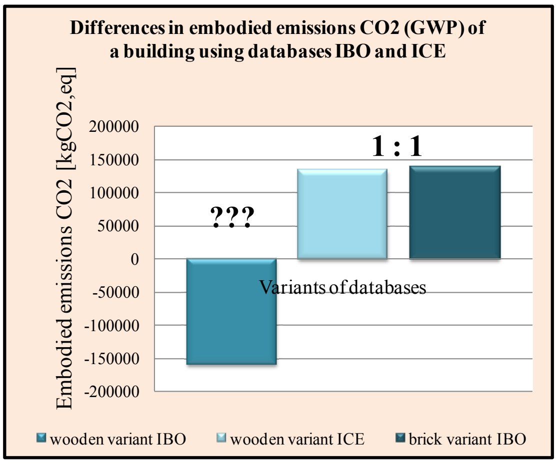


Fig. 5 Differences in embodied energy of building evaluated with IBO or ICE database

Fig. 6 Differences in embodied CO2 emissions of building evaluated with IBO or ICE database

From the previous figures it is clear that the results of the evaluation of materials from different databases may dramatically differ. This is a major problem for all these environmental assessments. It is therefore very necessary to establish a transparent and above all unified methodology for collecting the data. If you clearly knew the origin of the process of calculating the embodied energy and emissions, then the resulting values should reach a high degree of accuracy.

Until such a methodology does not exist, it is important during the acceptance and use of data from existing databases to recognize their differences and also try to use only one database, where it is likely that data will have the same basis.

Note: The methodologie mentioned above varies very much for the evaluation of wood. It is also because the ICE methodology does not include the values of embodied emission of the phase of timber growth, i.e. the phase when the trees are "withdraw" CO2 from the atmosphere. On the contrary, the IBO methodology includes this phase, and therefore the value of GWP is negative. The question is which method is more accurate because the reasonings of both methods are strong.

5 Evaluation of construction and material options of a building, using data from the IBO database

As it was already mentioned in the introduction, evaluation of building materials and constructions from environmental point of view is one of the important indicators of environmental quality of the building and can be done during the design phase. Such assessment should include not only the values of PEI and GWP, but also other parameters such as amount of materials entering the construction (non-renewable, renewable or recycled materials), as well as the output materials (recyclable, partly recyclable or non recyclable), and of course an important parameter is the total weight of the resulting structures.

The following study of higher education colleges in Telc [8] monitor differences of six variations of material, design and technological concepts. The resulting multi-criteria evaluation was performed in two ways - by comparing absolute (5.1) and weighted (5.2) values.

The were as follows:

- Variant 1: Masonry system POROTHERM
- Variant 2: Masonry system KS - QUADRO of calcium-silicate bricks and monolithic concrete floor slab
- Variant 3: monolithic concrete skeleton system with walls of porous concrete masonry blocks YTONG
- Variant 4: prefabricated concrete skeleton system with walls of clay brics
- Variant 5: heavy wooden skeleton
- Variant 6: combined system of monolithic concrete

The results of the analysis are described in the following articles.

5.1 Evaluation using a beam chart

Here the absolute values of the resulting environmental criteria relative to the reference variant 1 have been entered into the beam chart, viz. chart 4. If the areas of final polygons are cross-compared, we get the sequence of variants in environmental scale. In this case smaller area means better solution.

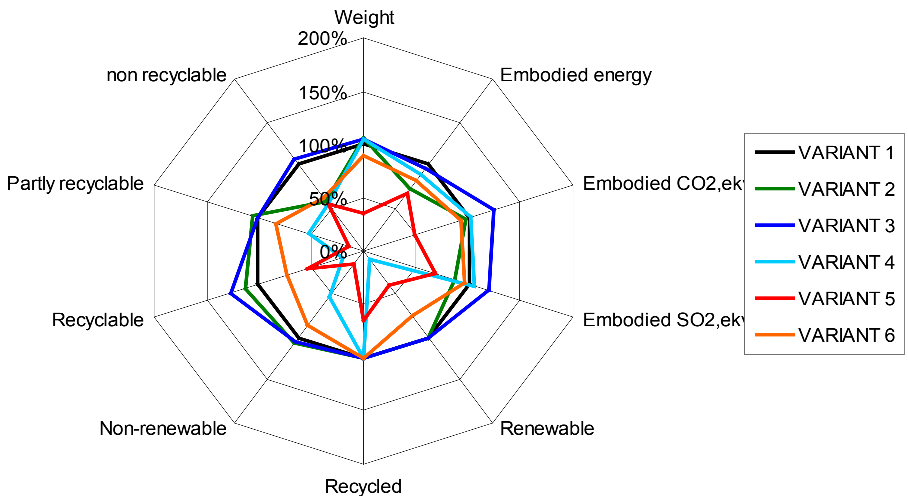


Fig. 7 Final evaluation using a beam chart

From this simple evaluation pro-and-cons of variants are clearly visible. Selection of the most optimal concept in terms of sustainability is easier.

5.2 Evaluation using weighting method

The second comparison was made using weighting method (figure 8). Each criterion was assigned to a weight proportion, expressing its "degree of importance." The resulting evaluation was made using several conversions of the absolute values to a characteristic function number, where min = 1 max = 0, i.e. the higher the resulting number the better the variant.

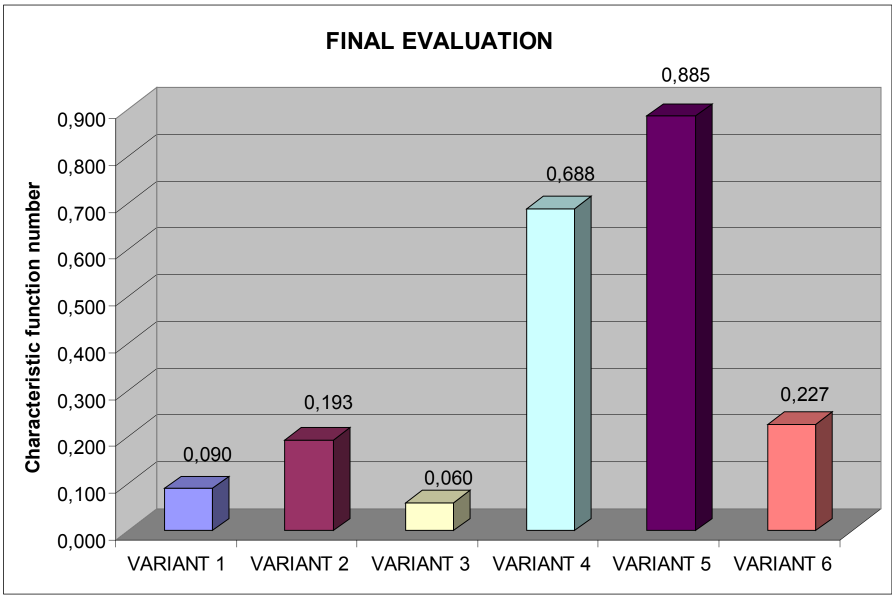


Fig. 8 Final evaluation using weighting

The differences of variants are clearly visible. Drawback of this method is the use of subjective weights.

Previous example shows us one of the options of evaluation of a building with the environmental parameters of building materials. If another material database was used for evaluation, the results would be more or less different. If there was a unified methodology of environmental evaluation of building materials, the results would reach higher accuracy.

6 Environmental catalogue of structures used in Czech Republic

At the moment there is no existing environmental catalogue of building structures mainly used in Czech Republic. This catalogue is currently being developed at the Faculty of Civil Engineering at CTU in Prague. It will be a web based system containing environmental as well as technical parametres of building materials and structures. Besides new construction it will include also historical structures.

The structure of the catalogue will be as follows:

- home page with transparent methodology and useful links with additional informations
- part A - catalogue of existing structures (horizontal, vertical, modern, historical...)
  - option 1 - sort structures by one of the criteria
    - environmental (embodied energy, CO2 emissions,...)
    - technical (thermal, acoustical properties,...)
    - type of structure (inside, outside, bearing wall...)
    - price
  - option 2 - detailed search according to user's preferences of criteria
    - individual weighting of criterias
    - using only some criteria required by user

- part B - composition of new structure according to individual parametres and requirements
  - creating new structure
  - modifying existing structure
  - modifying existing historical structure
- part C - simple calculator of environmental parametres of building structures according to the quantity of used material
- part D - transport - calculation of environmental impact of material transport

Nowadays developers, constructers, future users etc. are not quite interested to know what environmental impact have given building materials and what are other possibilities for structures with the same use but better environmental quality. This catalogue should help them at the beginning with environmental evaluation when they are interested.

7 Conclusions

A methodology is being created for conditions of the Czech Republic, that would allow us to obtain accurate environmental data of materials from the manufacturers, above all the value of embodied energy. Then a valuable database can be processed. To make this occur, it is necessary to gain access to data from the factories, which are often unavailable, insufficient and guarded. Overcoming these obstacles would facilitate any incentive of producers (e.g. optional certification) and users, who would then require a certain environmental quality of materials. The environmental catalogue can then be easily updated and used to select the optimal solution for the building structures.

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This research has been supported by grant of GA ČR 103/09/H095 „Sustainable Construction of Buildings and Sustainable Development of Urban Space".