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ANALYSIS OF BUILDINGS BASED ON THE MATERIALS LCA DATA

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ABSTRACT

Building industry as the principal sector to contribute to environmental burdens is accounted for production of the substantial amount of greenhouse or acidifying gasses, as well as is responsible for consumption of massive share of energy. Although the operation of buildings is liable for almost 80-90% of life-cycle energy consumed in buildings, the other phases of life cycle also require some special attention. Even if embodied material energy in the majority of buildings represents at about 10-20%, it may be a very significant fraction especially in modern energy efficient buildings.

Demands on higher standard and comfort of living has recently caused that building design has become more complicated and requires interdisciplinary cooperation of specialists from technical as well as non-technical disciplines. Selection of building materials is an important step which may influence not only amount of embodied energy or embodied CO2 and SO2 emission, but also future operation (usage stage) in terms of consumed energy and released emissions of CO2 and SO2.

In this paper, two alternatives of design of the same residential building were compared in terms of environmental performance of building materials used for building structures. Summarizing the results of the environmental evaluation the possibility to reach the reduction of embodied energy (by 16.2%), embodied CO2 (by 24.6%) and SO2 emissions (by 14.5%) has been proved through a simple change of material basis.

Key words: Environmental Assessment, Building Materials, Embodied Energy, Global Warming.

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Introduction

The building sector belongs to the principal industries responsible for the use of much energy and large and on the other hand is accounted for large quantity of carbon dioxide emissions. Construction sector also belong to principal consumers of raw materials and building industry is responsible for depletion of 40% of stone, gravel, and sand; use of 25% of wood; and for consumption of 16% of fresh water every year [1]. Processes in building construction including extraction, transport, manufacturing, assembling, as well as the use, deconstruction and disposal require energy, which results in CO2 generation. At the present, the building sector accounts for more than 40% of natural resource consumption, more than 1/3 of energy consumption and more than 1/3 of CO2 emissions, therefore these issues have become the focus of a major international interest how to preserve the global environment [2, 3]. In addition, the requirements on building are rising while supplies are being more limited.

There is the direct relationship between materials selection and environmental performance, in the sense that eco-design incorporates materials selection in order to reduce the environmental burdens [4]. Even EU has issued regulations aimed at the reduction of energy consumption, decrease of CO2 emissions and increase of the share of renewable energy resources (all by 20%) in order to mitigate a strong demand on materials and to minimize their negative impacts [5]. The energy efficiency legislations regulate new as well as existing buildings within the stage with substantial environmental impact – the usage phase mostly (operational energy need, greenhouse gasses emissions). Regarding the eco-design, the Life Cycle approach provides a suitable framework to analyse the overall environmental impact. Design of material composition of building in the early stages not only influences the initial environmental profile but also predetermines the behaviour in the usage stage.

This paper analyses the material basis of selected house and the environmental performance of building materials used in building structures. Comparison of environmental performance with second alternative of the same building with alternatively changed material composition of selected structures was performed. Evaluated parameters included weight of used materials, embodied energy and embodied CO2 and SO2 emissions within cradle to gate system boundaries.

Material and Methods

Description of Assessed Building

The conventional Slovak single family house selected for the evaluation consisted of the ground floor with terrace and 1st floor (inhabited attic) with 2 balconies. The rooms of the first floor included entrance hall, main hall with staircase, technical room, toilette, work room, large living room with kitchen and a larder. Configuration of the 1st floor consisted of hall with staircase, 3 bedrooms and bathroom.

For evaluation of environmental performance of building materials 2 alternative designs of the same house were selected. Assessment at the design level included analysis of material composition of 2 alternative designs (original (house A) and alternative one (house B)). Material composition of alternative building involves slight changes in the material basis. However, no major changes in material basis were done in order to keep the constructional system and technical solutions unchanged.

Underwork: In both alternatives, concrete was the principal material used for foundations. Macadam used in original building design was alternated with gravel in alternative scenario. In both cases, reinforced concrete slab were used, however in alternative building design the ratio of reinforcement was reduced to minimal level. In house A, concrete was the material of terrace and gutter sidewalk, while in house B gravel was used instead of certain amount of concrete.

Load Bearing and Partition Walls: Originally, perforated ceramic bricks were used for wall structures, while aerated concrete block were used in alternative scenario. As a result of different material characteristics, thinner external walls were used in alternative case (300 mm instead of 380 mm), while the thickness of indoor walls increased slightly (from 140 to 150 mm and 175 mm o 200 mm). This results in acquiring of larger indoor area, which is a positive fact. In relation to change of the thickness of wall structures, reinforced concrete lintels were changed in a subtle way.

Ceilings: In both cases, reinforced concrete slabs were used for ceiling. Minor changes in bond-beams were performed in house B resulting from the change of material of load bearing walls.

Roof: Roof designed originally keeps its shape and configuration also in the alternative solution. Wood was the main material of the framework (technically dried planned wood in original design and air-dried unplanned wood in alternative scenario). Roof weatherproofing in house A is secured by ceramic tiles, while concrete tiles are used in house B.

Thermal Insulation: To insulate foundations, XPS polystyrene was used (HFC foamed in original design and CO_2 foamed in alternative building design). In roof and lower ceiling glass wool was used. For façade insulation EPS-F was used in both cases, however 80 mm of insulation in original design was reduced to 70 mm due to improved insulation ability of load bearing material (aerated concrete) in alternative scenario. EPS was used in floors of both alternatives.

Surfaces: Indoor rendering consisted of lime-cement plasters in house A and gypsum plasters in house B. In house A the silicate plaster was used and was alternated by silicone plaster in house B. In both cases gypsum plasterboard was used for lower ceiling. For floors concrete layer was used. For walkway surface ceramic tiles, wood and laminate flooring were used.

Doors and Windows: In both alternatives wood frames with double glazed windows and argon filling were used.

Size description of both alternatives is presented in Table 1. Build up area is area defined with external walls. Useful area is area of rooms excluding walls (terrace and balconies are not included). Living area include only habitable rooms, e.g. living room, bedrooms etc. Floor area is total area of both floors defined by external walls. Build up cubature is the total cubature of the building.

TABLE 1. Description of buildings.

	Original (house A)	Alternative (house B)	Gain	Gain (%)
Build-up area (m^2)	83.91	83.91		
Useful area (m^2)	129.27	134.26	4.99	3.9%
Living area (m^2)	83.77	86.96	3.19	3.8%
Floor area (m^2)	167.82	167.82		
Cubature (m^3)	539.6	539.6		

Methodology

Environmental performance material analysis included calculation of volume and weight of used materials (m3 and kg), embodied energy (primary energy intensity – PEI – MJ), embodied CO2 emissions (global warming potential – GWP – kg CO2eq) and embodied SO2 emissions (acidification potential – AP – kg SO2eq) [6]. Evaluation consisted of separate analysis of materials divided into structures (underwork, vertical load bearing walls, partition walls, ceiling, roof, thermal insulation, surfaces and door & windows) and into material groups upon their manner (13 groups). To provide more relevant comparison of changed buildings the normalization of result by converting to area and cubature was performed.
In alternative building 14 changes in material basis comparing to original building were performed and environmental performance of building materials was calculated separately for both houses.

Results

Environmental Performance of Structures of Original Building

Analysis of environmental impact of building materials of house A divided into particular structures is presented in Figure 1. All illustrated in Figure 1, load bearing walls, underwork and thermal insulation were materials with the highest volume (54.7 m3, 51.5 m3 and 38.4 m3, respectively). The highest material weight was calculated for underwork (110.7 tons). The highest PEI was reached in load bearing walls (118.4 GJ), followed by underwork (110.2 GJ); the highest values of GWP (10.8 t CO2eq) as well as AP (33.5 kg SO2eq) were calculated for underwork.

Environmental Performance of Material Groups of Original Building

Environmental impact of materials divided into groups upon their manner to describe the ratio of materials and their contribution to particular environmental indicators is presented in Figure 2. As illustrated in Figure 2, concrete and ceramics were the materials with the largest volume ratio (33.3% for both). Concrete was the material with the highest weight percentage (61.7%). The highest PEI was calculated for ceramics and concrete and the share reached 35.0% and 31.3%, respectively. Concrete and ceramics were also materials with the largest contribution to global warming (39.7% and 24.7%, respectively) and to acidification (38.6% and 26.2% respectively).

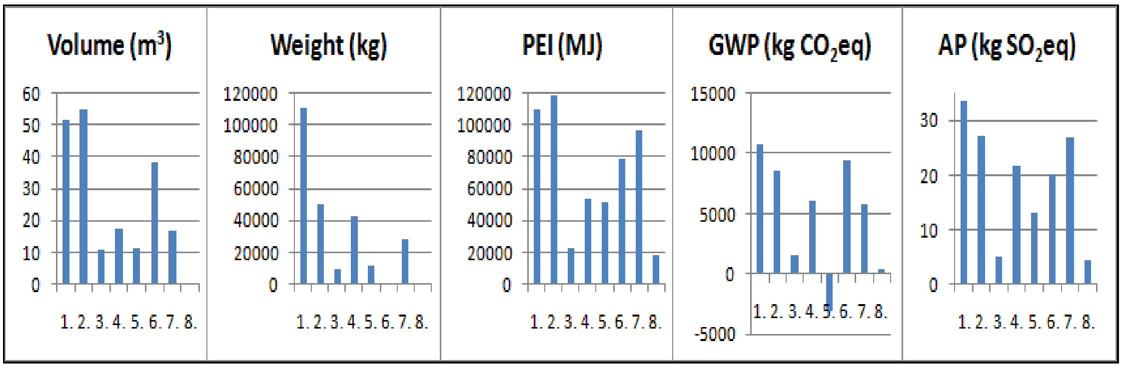

FIG 1. Environmental profile of particular structures of house A. 1-underwork, 2-vertical load bearing structures, 3-partition structures, 4-ceiling, 5-roof, 6-thermal insulation, 7-surfaces, 8-doors & windows.

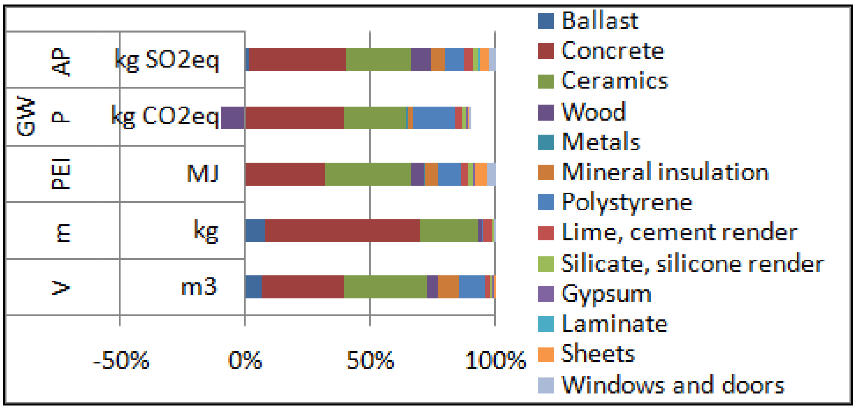

FIG 2. Contribution of material groups to environmental indicators in house A.

The use of wood involves the negative contribution of wood product to GWP (-9.3%) due to its ability of CO2 absorption during its growth [7, 8].

<u>Environmental Performance of Structures of Alternative Building</u>

Environmental performance of materials divided into particular structures of house B is presented in Figure 2. In alternative building design similar results were achieved, however slight changes appeared due to change of the material composition. Underwork, load bearing walls, and thermal insulation were materials with the highest volume (53.2 m3, 44.7 m3 and 37.0 m3, respectively). The highest weight was calculated for underwork (115.0 tons). The highest PEI value was also reached in underwork (102.4 GJ), followed by surfaces (96.2 GJ.) The highest GWP as well as

AP values were calculated for underwork (10.1 t CO2eq and 30.2 kg SO2eq, respectively).

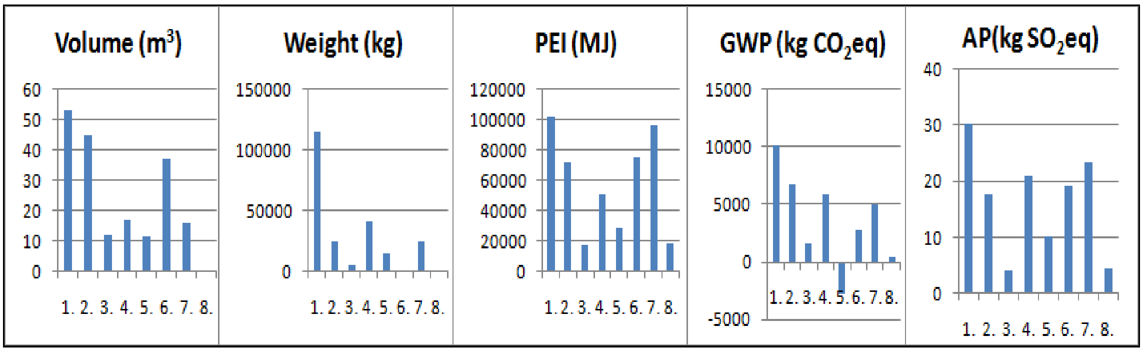

FIG 3. Environmental profile of particular structures of house A. 1-underwork, 2-vertical load bearing structures, 3-partition structures, 4-ceiling, 5-roof, 6-thermal insulation, 7-surfaces, 8-doors & windows.

<u>Environmental Performance of Material Groups of Alternative Building</u>

The ratio of materials and their contribution to particular environmental indicators is presented in Figure 4.

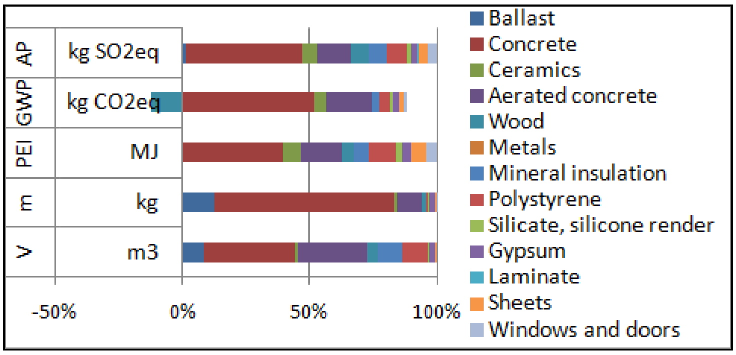

FIG 4. Contribution of material groups to environmental indicators in house B.

Concrete and aerated concrete materials represent those with the largest volume percentage (35.9% and 27.7%). The highest weight (70.6%), PEI (38.8%), GWP (51.7%) as well as AP (46.3%) was calculated for concrete. Contribution of wood to GWP reached the negative measure (-12.2%), which is a positive fact.

<u>Comparison of Original and Changed Material Composition</u>

In alternative building design a little change in material composition was done. In spite of relatively simple changes, environmental indicators reached lower values in the most of the parameters. Summarization of changes in material basis of original building (A) and alternative building (B) and comparison of the environmental impacts related is presented in Table 2.

TABLE 2. Environmental profile and comparison of original & alternative structures.

		Volume	**Weight**	**PEI**	**GWP**	**AP**
(1)	Underwork-ballast	m3	kg	MJ	kg CO2eq.	kg SO2eq.
(A)	Macadam	12.59	20136.00	2214.96	140.95	2.42
(B)	Gravel	12.59	22653.00	1812.24	90.61	1.13
	Balance*	0.0%	-12.5%	18.2%	35.7%	53.1%
(2)	Underwork-slab					
(A)	Reinforced concrete	9.53	23322.92	41457.41	3366.36	11.95
(B)	Reinforced concrete	9.53	23168.61	36477.47	3166.26	10.71
	Balance	0.0%	0.7%	12.0%	5.9%	10.4%
(3)	Underwork-gutter sidewalk					
(A)	Concrete only	4.41	10136.10	6993.91	1044.02	2.43
(B)	Concrete and gravel	6.04	12082.00	4361.82	599.36	1.66
	Balance	-37.1%	-19.2%	37.6%	42.6%	31.7%
(4)	Load bearing walls					
(A)	Perforated ceramic brick	50.70	40557.60	100988.42	7138.14	22.31
(B)	Aerated concrete block	41.27	16506.00	56780.64	5463.49	13.20
	Balance	18.6%	59.3%	43.8%	23.5%	40.8%
(5)	Lintels-load bearing walls					
(A)	Reinforced concrete	2.90	7100.94	12622.20	1024.93	3.64
(B)	Reinforced concrete	2.30	5635.51	10130.96	817.71	2.91
	Balance	20.7%	20.6%	19.7%	20.2%	19.9%
(6)	Partition walls					
(A)	Perforated ceramic brick	10.55	8439.20	21013.61	1485.30	4.64
(B)	Aerated concrete block	11.49	4594.00	15803.36	1520.61	3.68
	Balance	-8.9%	45.6%	24.8%	-2.4%	20.8%
(7)	Lintels-partitions					
(A)	Reinforced concrete	0.30	734.58	1305.75	106.03	0.38
(B)	Reinforced concrete	0.34	832.52	1479.84	120.16	0.43
	Balance	-13.3%	-13.3%	-13.3%	-13.3%	-13.3%
(8)	Ceiling-bond beams					
(A)	Reinforced concrete	3.10	7573.92	12952.44	1073.90	3.75
(B)	Reinforced concrete	2.49	6090.29	10620.71	871.31	3.07
	Reduction	19.7%	19.6%	18.0%	18.9%	18.2%
9	Roof-framework					
A	Technically dried wood-planned	6.62	3310.00	12776.60	-4753.16	6.82
B	Air-dried wood-unplanned	6.62	3574.80	6756.37	-5036.89	4.43
	Balance	0.0%	-8.0%	47.1%	6.0%	35.0%
10	Roof-weatherproofing					

A	Ceramic roof tiles	4.42	7960.32	36299.06	1592.06	5.57
B	Concrete roof tiles	4.56	10945.44	19592.34	2167.20	5.14
	Balance	-3.1%	-37.5%	46.0%	-36.1%	7.7%
11	Foundations thermal insulation					
A	XPS (HFC)	1.83	82.35	8564.40	6695.06	2.03
B	XPS (CO2)	1.83	78.69	8026.38	270.69	1.66
	Balance	0.0%	4.4%	6.3%	96.0%	18.4%
12	Façade thermal insulation					
A	EPS-F	11.83	236.64	23309.04	792.74	5.11
B	EPS-F	10.35	207.06	20395.41	693.65	4.47
	Balance	12.5%	12.5%	12.5%	12.5%	12.5%
13	Indoor plaster					
A	Lime-cement plaster	5.20	9360.00	14601.60	1432.08	5.24
B	Gypsum plaster	4.10	5330.00	13644.80	682.24	2.40
	Balance	21.2%	43.1%	6.6%	52.4%	54.2%
14	Outdoor plaster					
A	Silicate plaster	0.79	590.78	6837.24	283.57	2.02
B	Silicone plaster	0.79	590.78	6994.78	267.82	1.42
	Balance	0.0%	0.0%	-2.3%	5.6%	29.7%

Note: positive balance – Value in house A was reduced, negative balance – Value in house B was increased.

In the underwork, gravel was designed instead of macadam. Besides weight, all other indicators were reduced (1). The change in the reinforcement level of the slab (2), the reduction of all indicators was achieved. In the gutter sidewalk (3), where a certain amount of concrete was alternated with gravel, PEI, GWP and AP reached lower values. In load bearing wall, where aerated concrete block were used instead of perforated ceramic bricks the reduction of all indicators was reached (4). The use of different material of walls involved the change in the cappings (5), in which reduction of weight, PEI, GWP as well as AP was achieved. Although larger volume of aerated concrete in alternative scenario comparing to perforated ceramics in original scenario was used, the reduction of weigh, PEI and AP was reached (6). In capping of partition walls (7) the increase of all indicators was reached due to change of the thickness of alternative material. Environmental performance of bond beams (8) was also reduced. The change in the material of roof framework (9) involves higher weight, but lower measure of environmental indicators. For roof waterproofing (ceramics vs. concrete) the advantage of one material against other is disputable, as some indicators were reduced while the others were increased (10). The use of different XPS results in reduction of environmental burdens (11). The change of load bearing material also caused the change in the thermal insulation material of façade (12), which lower thickness was responsible for reduction of monitored indicators. Indoor rendering (13) was changed from lime-cement to gypsum plaster, what caused the decrease of weight, PEI, GWP and AP. Original outdoor plastering – silicate plaster was alternated with silicone plaster (14). Reduction of weight, GWP and AP was achieved.

Overall Environmental Profile of Original and Alternative Design

The overall environmental profile and the total reduction of assessed indicators is shown in Table 3.

TABLE 3. Overall environmental profile and environmental performance reduction.

	Volume (m^3)	**Weight (kg)**	**PEI (MJ)**	**GWP (kg CO2eq)**	**AP (kg SO2eq)**
Original	200.99	254185.69	549315.27	39519.08	152.04
Alternative	190.52	226933.05	460255.76	29791.32	130.05
Reduction	5.2%	10.7%	16.2%	24.6%	14.5%

As it is illustrated in Table 3, by using different material basis it is possible to reduce the amount of used materials (lower volume by 5.2% and weight by 10.7% was reached) and at the same time to reduce environmental burdens. Reduction in PEI, GWP as well as AP values was calculated ranging from 14.5-24.6% for particular environmental indicators.

Normalized environmental performance

TABLE 4. Normalized environmental performance.

Normalization	**Volume**	**Weight**	**PEI**	**GWP**	**AP**
Per build-up area	m3/m2	kg/m2	MJ/m2	kg CO2eq/m2	kg SO2/m2
Original	2.40	3029.27	6546.48	470.97	1.81
Alternative	2.27	2704.48	5485.11	355.04	1.55
Reduction	5.2%	10.7%	16.2%	24.6%	14.5%
Per useful area	m3/m2	kg/m2	MJ/m2	kg CO2eq/m2	kg SO2/m2
Original	1.55	1966.32	4249.36	305.71	1.18
Alternative	1.42	1690.25	3428.09	221.89	0.97
Reduction	8.7%	14.0%	19.3%	27.4%	17.6%
Per living area	m3/m2	kg/m2	MJ/m2	kg CO2eq/m2	kg SO2/m2
Original	2.40	3034.33	6557.42	471.76	1.81
Alternative	2.19	2609.63	5292.73	342.59	1.50
Reduction	8.7%	14.0%	19.3%	27.4%	17.6%
Per floor area	m3/m2	kg/m2	MJ/m2	kg CO2eq/m2	kg SO2/m2
Original	1.20	1514.63	3273.24	235.48	0.91
Alternative	1.14	1352.24	2742.56	177.52	0.77
Reduction	5.2%	10.7%	16.2%	24.6%	14.5%
Per cubature	m3/m3	kg/m3	MJ/m3	kg CO2eq/m3	kg SO2/m3
Original	0.37	471.06	1018.00	73.24	0.28
Alternative	0.35	420.56	852.96	55.21	0.24
Reduction	5.2%	10.7%	16.2%	24.6%	14.5%

Analysing the normalized values of assessed parameters, even higher ratio of reduction was achieved in the dependence on normalization area. Comparing original and alternative building, the normalized volume reduction reached 5.2%-8.7%, while normalized weight was reduced by 10.7%-14%. Reduction of normalized environmental indicators ranged from 16.2% to 19.3% in case of embodied energy, 24.6%-27.4% in case of embodied CO_2 and 14.5% to 17.6% for embodied SO_2.

Conclusion

Selection of appropriate building materials is a process specific for individual projects. The design of current buildings requires evaluation of number of parameters from different technical and non-technical branches, including environmental ones. Analysis of 2 alternative material solutions of the same building design has proven that by a simple change in material basis a certain reduction of environmental burdens in terms of environmental performance can be achieved. The importance of analysis of environmental profile is the most important in the project phase, as the changes in the design can be done easily and relatively quickly compared between each other unlike later when building is being erected.

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