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ENVIRONMENTAL ANALYSIS OF BUILDING MATERIALS OF HOMES IN SLOVAK REPUBLIC – A CASE STUDY

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ABSTRACT

Every human activity influences and changes the environment. Building industry together with production of food belongs to principal spheres which lead to depletion of natural resources and consuming of energy sources. Buildings participate on consuming of approximately 40% of total energy produced in highly developed countries. During the whole life cycle of buildings every individual element contributes to generation of greenhouse and acidifying gasses, waste creation, eutrophication, pollution of soil, water or air, ozone layer depletion and other negative effects. Massive amount of CO2 has its origin in energy processes which are required for heating, ventilation or cooling of buildings. However, beside operation of building, a selection of material basis influences environmental profile in enormous way. Exploitation of raw material, production of building materials and components, transportation to site, build-up, operation as well as demolition of structures require massive amounts of energy and result in change of local, as well as global climate. Life cycle assessment - the state-of-art method is used for evaluation of the potential environmental impact and quantifying of environmental performance of building materials. In this paper, parameters such as global warming potential, acidification potential, amount of primary energy and amount of used materials in building materials of 3 selected dwelling houses of contemporary Slovak build-up were evaluated using Life cycle assessment. In this case study building of similar size and constructional system were selected, described and analyzed, however building materials and components combinations varied to illustrate diverse span of results of environmental assessment. Amount of primary energy intensity reached values from 563218.0 MJ to 1360382.8 MJ in all 3 houses. Values of global warming potential

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were in rage from 38364.2 kg CO2eq to 76320.3 kg CO2eq. Acidification potential of building materials ranged from 214.38 kg SO2eq to 430.47 kg SO2eq. The total weight of used materials was in range from 257.7 to 451.4 tons.

Key words: Building materials, environmental performance, life cycle, global warming, primary energy, and acidification.

Introduction

As a result of massive building activity a noticeable deterioration of environment appeared, therefore a question of sustainability and sustainable building has become a point of interest of many researchers. Recently, activities to eliminate operational energy (energy required for heating, cooling, lighting etc.) have been more or less fulfilled, and low-energy or passive houses are being built round Europe. Another positive effect of minimization of operational energy needs is the reduction of greenhouse gases emissions, which have origin mostly in combusting of fossil fuels. However, changes in construction system which participate in reduction of requirements on operational energy usually require utilization of larger amounts of materials (thermal insulation materials above all). When taking the whole life cycle of building into consideration, not only operational phase, the use of larger amounts of materials leads to the increase of the overall embodied energy (primary energy) and contributes to the generation of larger amounts of CO2 or SO2 emissions. When comparing operational energy required for heating and embodied energy of finished building, the embodied energy only represents 3-7 % from the total energy in the building from last century (20s of 19th century until today's standard houses, regards 80 years or operation). However, in progressive houses with minimized operational energy, the embodied energy represents up to 20 % of the total energy, therefore there is a opportunity to perform further minimization of negative environmental impact by selecting proper building materials with less negative impact [1-3]. In this paper, the analysis of material basis of 3 selected houses and their environmental profile in terms of building materials is presented. Evaluation included amount of primary energy from non-renewable sources, amount of emissions of greenhouse gases, quantity of acidifying gasses and weight of used materials.

Materials and Methods

Description of assessed buildings

Assessed building selected to illustrate the environmental impact of building materials were chosen to have similar attributes and to provide the same standard of individual Slovak build-up. All three buildings are without basement, garage and with ground floor (day-time part) and second floor (inhabited attic – night-time part). The size of building varies, however each house is suited for a family of 4-6 members. Characteristics of areas of evaluated buildings are summarized in table 1.

Table 1: Parameters of the assessed buildings.

	House 01 JM	House 02 LF	House 03 ZK
Build up area (m^2)	197.25	163.2	108.8
Useful area (m^2)	240.05	208.32	135.48
Living area (m^2)	125.93	88.19	68.67
Total cubature (m^3)	811.1	651.38	552.24
No. of inhabitants min	5	4	4
No. of inhabitants max	7	6	6

Characterization of material basis

Excavations and foundations: Organic soil and soil for excavations was removed. Objects are founded on concrete strips. Base plate of each house is made of reinforced concrete. Gravel is used under the foundations. Damp proof course of house 01 and 02 is made of polymeric foil; however EPDM is used in house 03.

Vertical load-bearing walls: Load-bearing walls, internal as well as external, are designed of perforated ceramic brick (400 mm and 250 mm thick in house 01; 440 mm and 300 mm thick in house 02). Load bearing walls of house 03 are made of aerated concrete blocks of thickness of 375, 300 and 250 mm. Capping and bond beams are made of reinforced concrete.

Partition structures: Material of partition walls (non-load bearing function) is the same as the material of external walls (ceramics in house 01 & 02 and aerated concrete in house 03).

Horizontal load-bearing constructions - ceiling: Ceilings of each house are designed of reinforced concrete.

Roof: The framework of roofs in every house is made of air-dried wood. Another wood material is applied to create the shuttering. Roof covering is however different for each house - in house 01 and 02, the ceramic tiles are used. Concrete roofing tiles are used as a material roof weather-proofing in house 3.

Thermal insulation: In house 01 polystyrene (EPS) is used in the floors and glass wool is used as a roof insulation and insulation of façade (external walls with thermal insulation create the insulation system). Glass wool is the thermal insulation material of floors in house 02. Mineral wool is used in the roof and CO2 foamed XPS (polystyrene) insulates the foundations. In this house the 440 mm thick external walls are used, therefore no other thermal insulation of façade is necessary. In house 03 perlite is used as thermal insulation material (roof, floors). Mineral wool is also used and XPS (CO2 foamed) insulates the peripheral foundation strips.

Façade surfacing: Silicate plaster with glass-textile mash and façade adhesive is used in house 01. Silicate plaster is also used in house 02. Cement fiberboards are also used in house 02. In house 03 silicate plaster is also the material of surface.

Surfacing: Walkway surface material of house 01 is designed of laminate and ceramic floor tiles. Lime-cement plastering material is also used. In house 02, the walkway surface is made of laminate boards and ceramic tiles. Lime-cement and lime plasters are the material of surface of indoor walls and ceilings. Gypsum plasterboard is also used. Walkway surface of floor construction of house 03 is created by wood board floor and ceramic tiles. Wood fiberboard is also used in the house 01. Plasters are of lime-cement and lime-gypsum material. Gypsum plasterboard is also used for surfacing of lower ceilings.

Doors and windows: Plastic frames and triple glazed windows with argon filling are used in house 01. In house 02 wooden windows with triple glazed boards are used. Triple glazed windows in plastic frames are used in house 03. Filling is made of Ar.

Methodology

For evaluating of environmental performance of building materials the Life Cycle Assessment appears to be one of the most complex methods. Parameters such as Primary Energy Intensity (PEI – MJ), Global Warming Potential (GWP – kg CO2eq), Acidification Potential (AP – kg CO2eq) and amount of used materials (Weight - kg) were included into assessment. Normalization of result was also performed in order to provide more accurate comparison of different buildings.

In this case study a MS Excel tool, which contains the data from IBO database, was used [4]. Building materials were divided into structures (9 groups of components combinations, e.g. vertical load-bearing walls, thermal insulation, roof, etc.) and into several groups of materials on the basis of their nature (e.g. concrete, ceramics, mineral insulation, polystyrene etc.) [5]. Input values (quantity of used materials - volumes and areas) were used to calculate the overall environmental profile of particular building.

Results

Overall environmental profile of houses

The overall environmental profile with total values of weight, PEI, GWP and AP of all three houses is presented in table 2. Quantity of used materials, as well as environmental indicators reached the highest values in house 02 as a result of relatively larger size of building comparing to others.

Table 2: Environmental profile of houses.

	PEI (MJ)	GWP (kg CO2eq)	AP (kg SO2eq)	Weight (kg)
House 01 JM	1360382.8	76320.3	430.47	451445.3
House 02 LF	761934.5	38364.2	214.38	304562.8
House 03 ZK	563218.0	40813.9	204.46	257734.9

<u>Environmental profile of particular structures</u>

For more detailed characterization of the environmental impact the building materials were divided into structures. Environmental performance of particular structures is presented in figure 1.

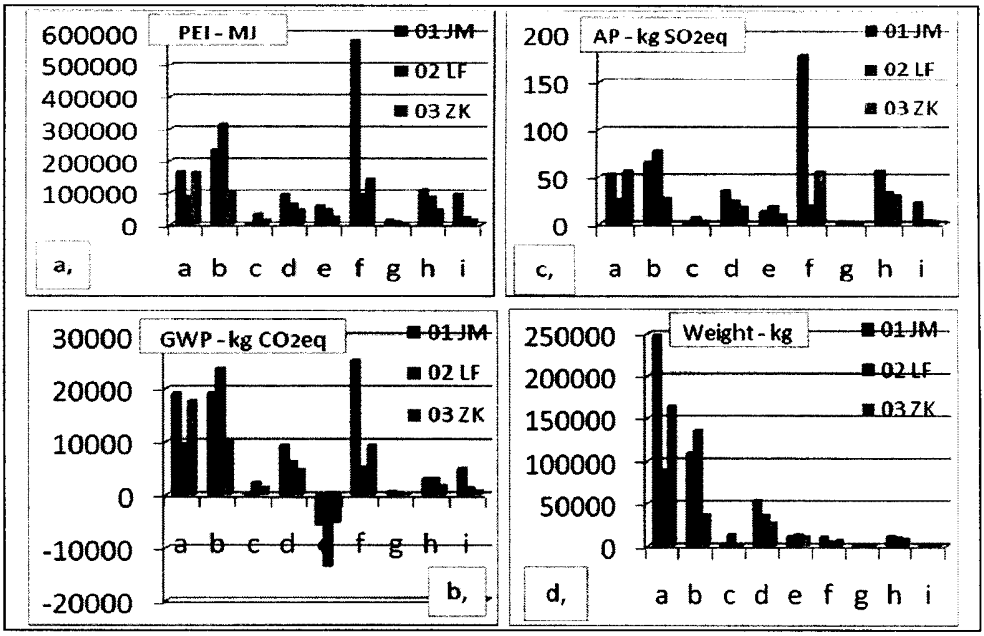

Figure 1: Environmental profile of particular structures.

As a reason of the high amount of used material of foundation and load bearing walls the PEI value (fig. 1a) in all three houses was relatively high (from 88636.9 MJ to 166708.8 MJ – for foundations and from 103068.0 MJ to 235242.1 MJ – for bearing walls). However, the highest primary energy consumption was estimated in thermal insulation of house 01 (577487.7 MJ) due to intense use of thermal insulation (XPS in foundation, glass wool for façade etc.). As expected, high values of GWP (fig. 2b) were reached in materials of foundations and load-bearing walls (from 9563.8 to 23801.2 kg CO2eq), however, again the highest value of GWP of all evaluated structures was reached for thermal insulation of house 02 (25383.7 kg CO2eq). An interesting fact is the negative contribution to global warming of materials of roof, with GWP values ranging from (-13497.4) to (-5221.8) kg CO2eq. This occurs due to woods ability of absorption of carbon dioxide during its growth and results from cradle to gate system boundaries. Acidification potential was remarkable in materials of foundations, load bearing walls, surfaces and thermal insulation (fig. 2c). The highest total value of acidification potential was calculated for thermal insulation of house 01 (178.15 kg SO2eq). As illustrated in fig. 1d, the highest weight of used materials was calculated for foundations (from 89.6 to 248.5 tons) as a result of high bulk density and high quantity of used material (concrete, gravel).

<u>Environmental profile of particular building materials groups</u>

To create the environmental profile of building materials upon the materials' manner the percentage of particular parameters was calculated.

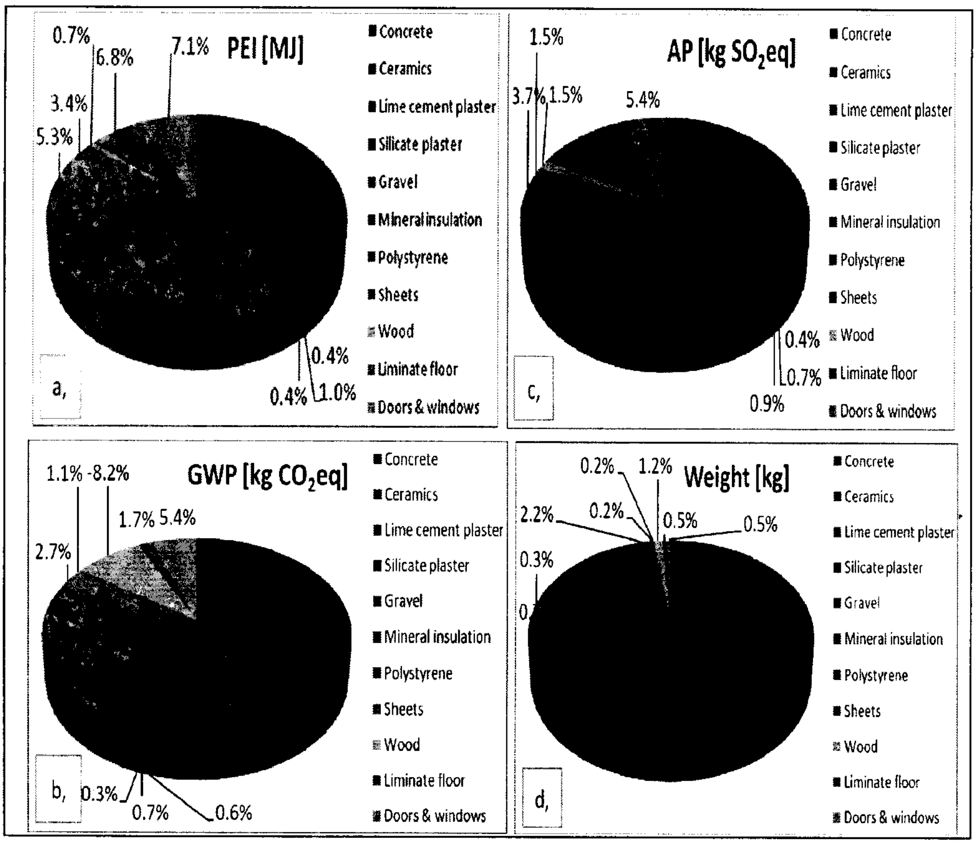

Figure 2: Ratio of contribution of materials to environmental indicators of house 01.

In house 01, the concrete is the material with the highest weight ratio (62.7%) and with the highest contribution to global warming (40.4%), however the material with the most negative effect on environment is the mineral insulation with the highest PEI ratio (37.1%) and the highest AP value (37.7%). Negative GWP (-8.2%) was determined for wood products.

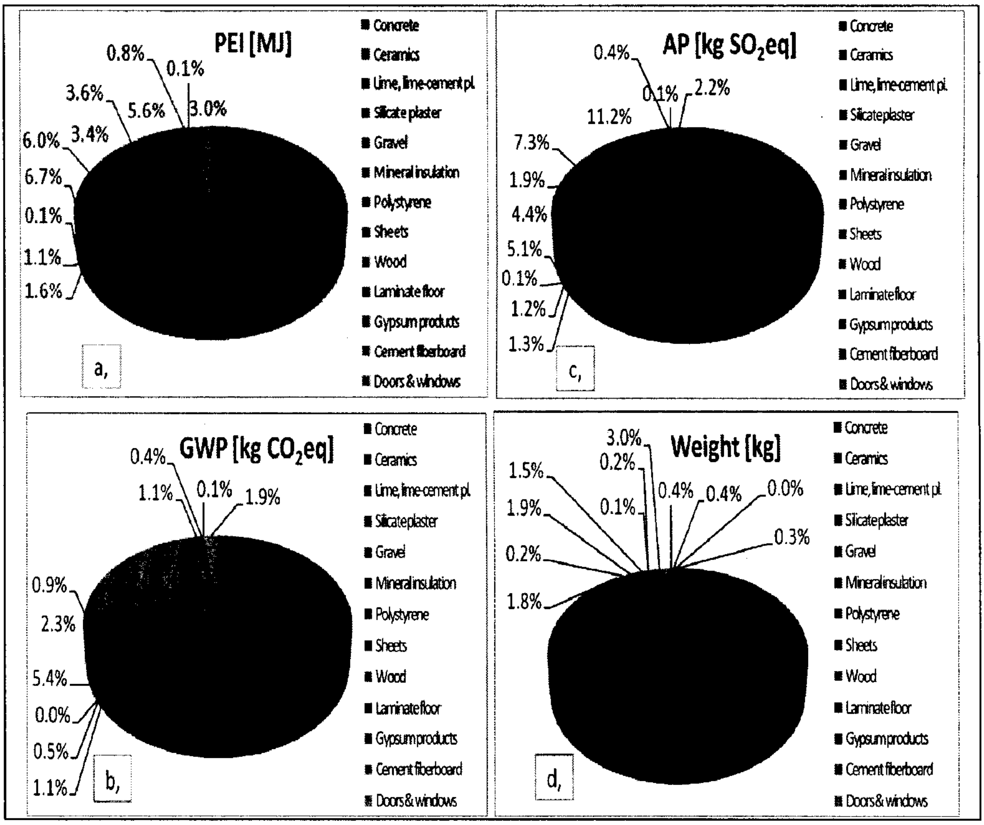

Figure 3: Ratio of contribution of materials to environmental indicators of house 02.

In house 02 concrete and ceramics are the most used materials with 48.7% and 41.4% respectively. The highest primary energy consumption vas calculated for ceramics (44.9%), as well as the highest GWP (34.6%) and AP value (34.6%). A negative contribution to global warming was recorded for wood structures (-21.4%).

Concrete was material with the highest mass (71.6%) in the house 03. Most negative environmental profile was also calculated for concrete with 38.4% share of primary energy intensity 44.9% contribution to global warming and 38.6% contribution to acidification. Negative CO^2 emissions of wood structures reached 12.2%.

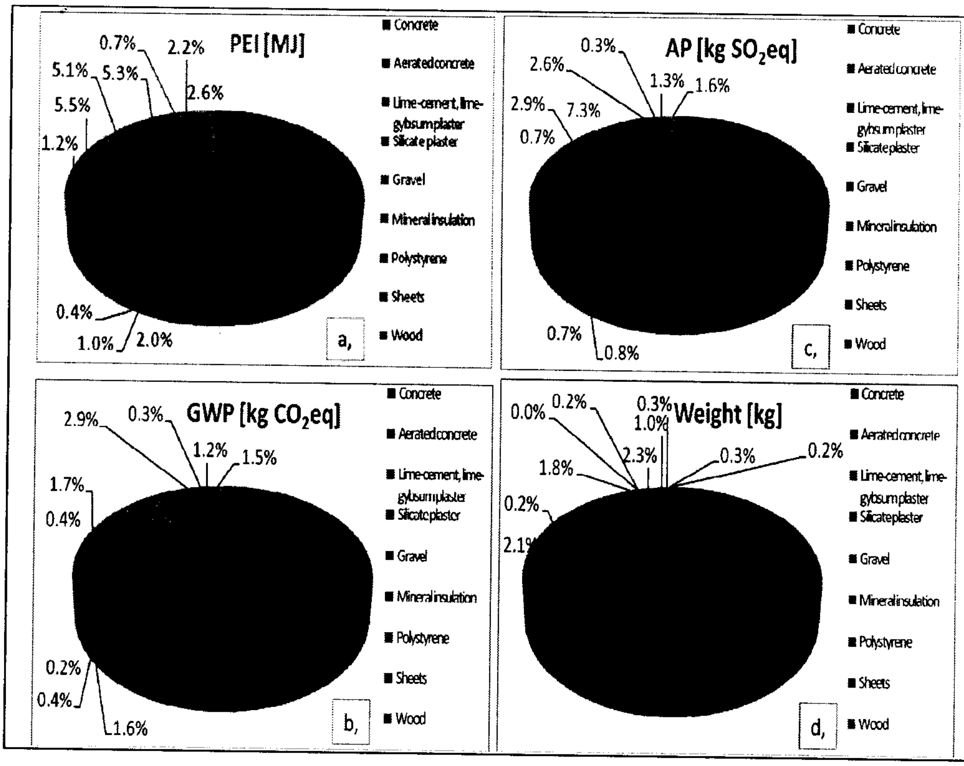

Figure 4: Ratio of contribution of materials to environmental indicators of house 03.

Normalized environmental profile

Normalized values of environmental performance provide an easier comparison of same structures in various houses. Absolute values may reach high values; however normalized values may be lower when converted to values per m^2, m^3 or per person. Transformed values in the dependence on the area cubature or inhabitant of buildings are presented in table 3.

As presented in table 3, the most negative influence on the environment in terms of used materials was calculated for house 01. Normalized parameters (both areal and cubical) of PEI, GWP and AP reached the highest values in this house. The lower measure reached normalized PEI, GWP and AP values in houses 02 and 03. However, it is rather difficult to choose the house with the least negative effect on environment because of the different material basis or different architecture. Weight-normalized values of total environmental performance (presented in table 4) are provided to illustrate, that the house with the highest negative material influence on environment was house 01.

Table 3: Normalized environmental profile of houses.

Normalization of PEI			
PEI	**01 JM**	**02 LF**	**03 ZK**
Per build up area (MJ/m^2)	6896.7	4668.7	5176.6
Per useful area (MJ/m^2)	5667.1	3657.5	4157.2
Per living area (MJ/m^2)	10802.7	8639.7	8201.8
Per total cubature (MJ/m^3)	1677.2	1169.7	1019.9
Per capita min - (MJ/inh.)	340095.7	190483.6	140804.5
Per capita max - (MJ/inh.)	194340.4	126989.1	93869.7
Normalization of GWP			
GWP	**01 JM**	**02 LF**	**03 ZK**
Per build up area (kg $CO2eq/m^2$)	386.9	235.1	375.1
Per useful area (kg $CO2eq/m^2$)	317.9	184.2	301.3
Per living area (kg $CO2eq/m^2$)	606.1	435.0	594.3
Per total cubature (kg $CO2eq/m^3$)	94.1	58.9	73.9
Per capita min - (kg CO2eq/inh.)	19080.1	9591.1	10203.5
Per capita max - (kg CO2eq/inh.)	10902.9	6394.0	6802.3
Normalization of AP			
AP	**01 JM**	**02 LF**	**03 ZK**
Per build up area (kg $SO2eq/m^2$)	2.18	1.31	1.88
Per useful area (kg $SO2eq/m^2$)	1.79	1.03	1.51
Per living area (kg $SO2eq/m^2$)	3.42	2.43	2.98
Per total cubature (kg $SO2eq/m^3$)	0.53	0.33	0.37
Per capita min - (kg SO2eq/inh.)	107.62	53.59	51.11
Per capita max - (kg SO2eq/inh.)	61.50	35.73	34.08
Normalization of weight			
Weight	**01 JM**	**02 LF**	**03 ZK**
Per build up area (kg/m^2)	2288.7	1866.2	2368.9
Per useful area (kg/m^2)	1880.6	1462.0	1902.4
Per living area (kg/m^2)	3584.9	3453.5	3753.2
Per total cubature (kg/m^3)	556.6	467.6	466.7
Per capita min - (kg/inh.)	112861.3	76140.7	64433.7
Per capita max - (kg/inh.)	64492.2	50760.5	42955.8

Table 4: Weight-normalized environmental profile of houses.

	MJ	**GWP kg (CO2eq/kg)**	**AP (g SO2eq/kg)**
01 JM	3,013	0,169	0,954
02 LF	2,502	0,126	0,704
03 ZK	2,185	0,158	0,793

Conclusion

Results of case study illustrate the environmental profile of three houses and comparison of the environmental performance of structures and building materials. Results presented are difficult to be interpreted, e.g. overall environmental impact of constructions of heavier material (foundations or load bearing walls) is relatively negative - high values of PEI, GWP or AP are reached due to high amount of used materials, therefore these materials are marked as the most negative ones. On the other hand, e.g. thermal insulation is material with relatively low weight but with high negative impact on environment. With selection of proper material it is also possible to reach the negative CO2 emission and contribute to elimination of greenhouse effect. A more precise analysis and more similar case studies are necessary to provide the comprehensive assessment of Slovak buildings.

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