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Environmental Evaluation of Building Materials of 5 Slovak Buildings

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Abstract

Building activity has recently led to the deterioration of environment and has become unsustainable. Several strategies have been introduced in order to minimize consumption of energy and resulting CO_2 emissions having their origin in the operational phase. But also other stages of Life Cycle should are important to identify the overall environmental impact of construction sector. In this paper 5 similar Slovak buildings (family houses) were analyzed in terms of environmental performance of building materials used for their structures. Evaluation included the weight of used materials, embodied energy and embodied CO_2 and SO_2 emissions. Analysis has proven that the selection of building materials is an important factor which influences the environmental profile. Findings of the case study indicated that materials like concrete, ceramic or thermal insulation materials based on polystyrene and mineral wool are ones with the most negative environmental impact.

Key words: environmental assessment, environmental profile, embodied energy, embodied CO_2

1 Introduction

Human activities including construction of buildings which have led to the deterioration of environment have recently become a point of interest of professionals from various branches [1]. After more than 50 years of research the building sector is still responsible for many harmful issues. Pollution of soil, water and air resulting from unsustainable use of massive amount of raw materials are the principal issues of building industry. For example, the construction 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 [2]. The intensive use of energy originating from fossil fuels results in the generation of greenhouse gasses emissions. Contemporary buildings of developed countries are responsible for 1/4-1/2 of total energy used [3]. To mitigate the climate change the reduction of CO_2 emission by 50% by 2050 needs to be achieved [4]. In addition, the requirements on building quality are rising while supplies remain more limited. Many progressive buildings require the use of high amount of materials (e.g. thermal insulation, membranes) or improving of quality of indoor environment involves the utilization of hi-tech appliances. To reduce such a strong demand and to minimize the negative impacts, the European Union has issued a number of acts aimed at the reduction of energy consumption by 20%, decrease of CO_2 emissions by 20%, and increase of the share of renewable energy resources to 20%. The Directive on Energy Performance of Buildings requires implementing energy efficiency legislations for new, as well as existing buildings [5, 6].

The majority of regulations deal with the usage phase (operational energy and greenhouse gasses emissions). Due to long life span of buildings the usage of buildings is the stage with substantial environmental impact. However, concerning the buildings life cycle, also other aspects are included to identify the overall environmental impact. As universal optimal design does not exist, the individual analysis is necessary [7]. Design of material composition of building in the early stages predefines the future behaviour (usage stage) and thus influences the overall environmental performance [8].

This paper is aimed at analysis of environmental performance of building materials of 5 family houses. Materials of selected buildings were analyzed in terms of amount of used materials, embodied energy and embodied CO_2 and SO_2 emissions within cradle to gate system boundaries.

2 Material and methods

2.1 Description of the evaluated buildings

Five similar buildings (family houses) were selected for evaluation of environmental performance of building material. Each single storey building is with a gabled roof, has no basement and is suitable for 3-6 inhabitants. Some of the houses have roofed entrance, terrace, garage or gutter side walk. Areal and volumetric characterization of building consists of the ‘total build-up area’ (includes the area of house itself, terrace, leeward, gutter sidewalk), ‘computing build-up area’ (area of house including roofed terrace and leeward), ‘total useful area’ (area of rooms without walls and pillars, including terrace and leeward), ‘computing useful area’ (indoor room area without walls and pillars), ‘living area’ (living floor space) and ‘build-up space’ (volume of building). Configuration of compared buildings together with areal and cubical size description is presented in table 1.

Table 1: Configuration of assessed buildings

House	Ground floor	Roofed entrance	Terrace	Garage	Sidewalk	Build-up area (m^2)	Useful area (m^2)	Living area (m^2)	Build-up cubature (m^3)	Inhabi-tants min (capita)	Inhabi-tants max (capita)
1	+	-	-	-	+	145	122.09	80.99	653.4	3	6
2	+	+	+	-	+	158.8	123.28	66.32	642.1	3	6
3	+	+	+	-	+	191.95	126.94	76.8	875.1	3	5
4	+	-	-	-	+	107.09	80.1	43.6	607.7	3	4
5	+	+	+	+	+	181.99	140.69	75.55	855.3	3	6

2.2 Material composition of the assessed buildings

In order to illustrate the representative environmental profile of Slovak build-up 5 similar conventional buildings with standard material compositions were selected for the evaluation.
The building foundations consisted of concrete on gravel layer. Damp proof course was made of polymer bitumen sheet, bitumen-aluminium sheet or PVC foil. Perforated ceramic bricks or aerated concrete blocks broadly used for masonry walls (external, internal, partitions) of Slovak houses were used in the evaluated buildings [9]. Lintels and bond-beams are designed of reinforced concrete. As ceiling construction materials were used: reinforced concrete, prefab ceramic block on prefab concrete joist or wood. However, for houses with ground floor only (bungalow), where the attic is not habitable the wood is preferred alternative and was used in 3 of 5 houses. Framework of roof is without exception constructed of wood, while roofs weatherproofing consists of wider range of materials (concrete or ceramic tiles, bitumen or metal sheets). Various types of thermal insulation were used for insulation of foundations, floors, walls, ceilings and roof. Polystyrene (XPS, EPS) and mineral insulation (rock and glass wool) were used. Materials of surfaces included lime or lime-cement indoor plasters, silicate or silicone external plasters, wide range of floor surfaces (ceramics, laminate, wood, concrete) or gypsum plasterboard used for lower ceiling mostly. Standard doors and windows frames were made of wood or plastic with double or triple glazing. Characterization of materials of assessed houses is presented in table 2.

Table 2: Material composition of assessed buildings

	House H1	House H2	House H3	House H4	House H5
Under-work	concrete foundations, base plate - reinforced concrete, gravel, PVC foil, geotextile	concrete foundations, concrete base plate, gravel, polymer bitumen sheet	concrete foundations, concrete base plate, concrete hollow blocks, gravel, polymer bitumen sheet, reinforced concrete stairs	concrete foundations, concrete base plate, gravel, PVC foil, geotextile	concrete foundations, base plate-reinforced concrete, concrete hollow blocks, gravel, aluminum-bitumen sheet, reinforced concrete staircase
Vertical walls	perforated ceramic bricks, lintels -reinforced concrete	perforated ceramic bricks, lintels-reinforced concrete	aerated concrete blocks, lintels, pillars-reinforced concrete	aerated concrete blocks, lintels - reinforced concrete	perforated ceramic bricks, lintels, pillars-reinforced concrete
Partition walls	perforated ceramic bricks, lintels -reinforced concrete	perforated ceramic bricks, lintels -reinforced concrete	aerated concrete blocks, lintels - reinforced concrete	aerated concrete blocks, lintels - reinforced concrete	perforated ceramic bricks, lintels - reinforced concrete
Ceiling	bond beams-reinforced concrete, wood ceiling, OSB	bond beams-reinforced concrete, ceramic ceiling, concrete	bond beams, girders-reinforced concrete, wood ceiling	bond beams-reinforced concrete, wood ceiling, OSB	bond beams-reinforced concrete, wood ceiling, OSB
Roof	wood framework, ceramic tiles	wood framework, bitumen sheeting	wood framework, ceramic tiles, galvanized sheet	wood framework, ceramic tiles, steel sheet	wood framework, concrete tiles, galvanized sheet

Thermal insulation	XPS (foundations), EPS (floors), rock wool (facade), glass wool (ceiling, roof)	XPS (foundations), rock wool (facade, floors, ceiling)	rock wool (floors, ceiling, thermal bridges), XPS (floors)	EPS (facade, floors), glass wool (ceiling)	XPS (foundations), rock wool (facade, ceiling), EPS (floors)
Surfaces	concrete screed, wood floor, ceramic tiles, lime cement plaster, silicate plaster, glass-textile mash, gypsum plasterboard	concrete screed, laminate floor, ceramic tiles, lime cement plaster, silicate plaster, glass-textile mash	concrete screed, ceramic tiles, wood logs, wood floor, concrete tiles, lime cement plaster, silicate plaster, gypsum plasterboard	concrete screed, ceramic tiles, concrete screed, ceramic tiles, lime cement plaster, silicate plaster, glass-textile mash	concrete screed, ceramic tiles, wood paneling, wood floor, lime cement plaster, silicate plaster, glass-textile mash, gypsum plasterboard
Doors, window	wood-aluminum frame, double glazed	wood frame, double glazed	plastic, double glazed, argon	wood frame, double glazed, argon	wood frame, double glazed, argon

2.3 Methodology

In the study 5 dwellings were analyzed in terms of environmental performance of building materials. For calculation, volumes (areas for some materials) were used for input calculation of weight of materials (kg), embodied energy (primary energy input PEI – MJ), embodied CO_2 emissions (global warming potential GWP – kg CO_2eq) and embodied SO_2 emissions (acidification potential AP – kg SO_2eq) within cradle to gate boundaries (from extraction of raw materials to leaving of final factory gate). Materials were analyzes as used structures (8 groups: underwork, vertical load bearing walls, partition walls, ceiling, roof, thermal insulation, surfaces and door & windows). Environmental performance was also evaluated for materials classified into groups upon their manner (11-14 material groups) and overall assessment for whole buildings was also included. Input calculation data of environmental properties were extracted from broadly used database [10-12]. In order to provide the relevant comparison of buildings the normalization of values was performed by transposing calculating the relative values (per m^2 or m^3).

3 Results

3.1 Overall environmental profile

The total values of assessed parameters calculated according to amount of used materials for particular houses are presented in table 3.

Table 3: Overall environmental profile

	H1	H2	H3	H4	H5
Weight - kg	238428.7	314228.6	366986.6	175189.2	371087.6
PEI – MJ/kg	2.290	1.821	1.705	2.053	2.194
GWP - kg CO_2eq/kg	0.130	0.139	0.100	0.060	0.110
AP - g SO_2eq/kg	0.650	0.585	0.532	0.587	0.700

The highest weight of structures, together with the highest AP was reached in house H5 which was one of the largest. The highest PEI was calculated for building H1 and the highest GWP was calculated for house H2. The difference between the lowest and the highest value was 52.8% of weight (H4-H5), 25.6% of PEI (H3-H1), even 56.5% for GWP (H4-H2) and for AP 23.9% (H3-H5).

3.2 Environmental performance of particular structures

For a more precise analysis the materials were classified into structures. Particular parameters were evaluated for each structure to obtain the contribution of particular parts of houses (figure 1).

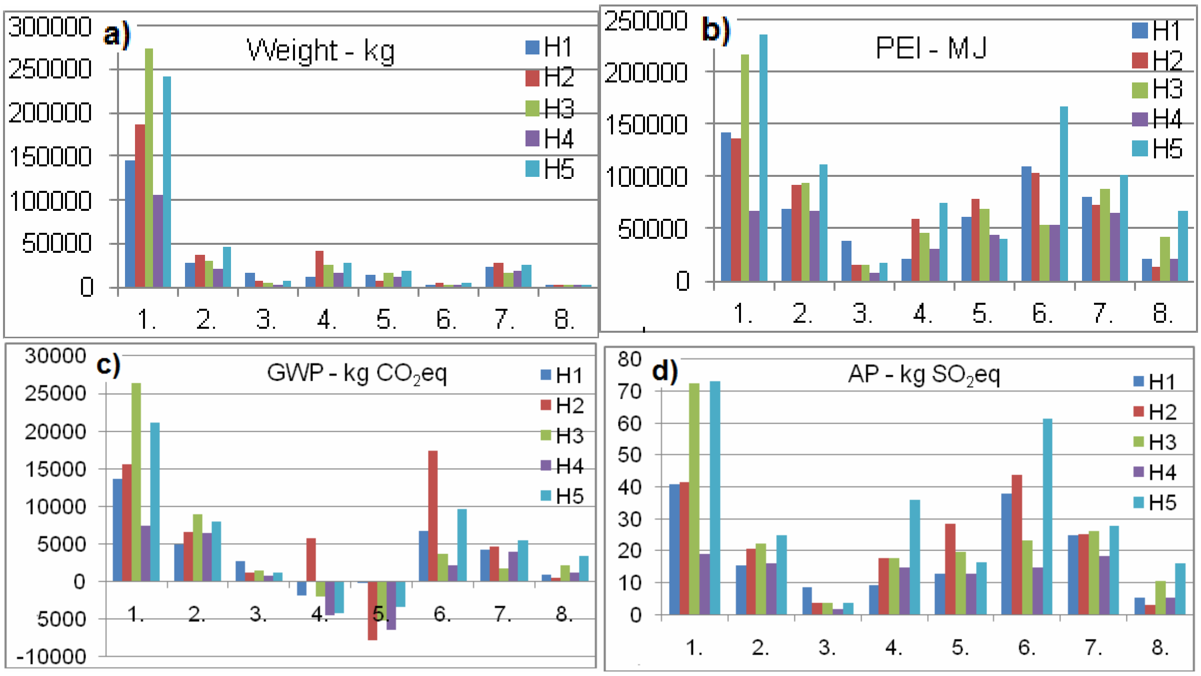

Figure 1: Environmental profile of particular structures (a,-weight, b,-PEI, c,-GWP, d,-AP; 1-underwork, 2-vertical load bearing structures, 3-partition structures, 4-ceiling, 5-roof, 6-thermal insulation, 7-surfaces, 8-doors & windows)

As illustrated in figure 1a, the underwork was the heaviest structures in all 5 buildings (105195.0 -272868.6 kg). This was caused due to use of large amount of materials with high bulk density (concrete, gravel). Fairly heavy were also the materials of vertical load bearing walls (external as well as internal), which consist of perforated ceramic bricks or aerated concrete blocks with reinforced concrete capping. High level of used materials was calculated for ceiling, particularly in house 2, in which ceramic ceiling was used unlike wooden ceiling in houses H1, H3-5.

As a result of large quantity of materials for underwork, the highest PEI level (figure 1b) was reached for the same structures (67366.8 – 236134.7 MJ). The exception is vertical load bearing structures of house H4, in which smaller foundations together with relatively large amount of external and internal walls were used; therefore the highest PEI was calculated for vertical load bearing structures (67964.9 MJ). Relatively high PEI value (ranging from 103695.7 to 167218.1 MJ) was calculated for thermal insulation especially in houses H1, H2 and H5, in which high quantity of thermal insulation was used (facade insulation, insulating of foundations, floors, ceiling or roof).

Considering the embodied CO_2 emissions, the largest values of GWP were calculated for underwork of and were in range from 7333.7 to 26334.5 kg CO_2eq (figure 1c). This was caused by utilization of large amount of concrete and gravel. Relatively high GWP was calculated also for thermal insulation and load bearing walls. Remarkable is the negative contribution of materials of roof in the most of the ceilings (H1, H3-5) to global warming potential. In these structures the large amounts of wood was used, so GWP reached the negative values (-7779.6 to -169.2 kg CO_2eq).

The largest level of AP (figure 1d) was calculated for underwork of houses H3 (AP=72.34 kg SO_2eq) and H5 (AP=72.34 kg SO_2eq). The second highest contribution to acidification was reached in thermal insulation materials of houses H2 and H5 ranging from 43.71 to 61.45 kg SO_2eq.

3.3 Environmental performance of particular materials used

To find out the share of particular building materials group and percentage of its contribution to particular impact category the building materials of each building were divided into groups. Percentage of particular impact categories for house H1 is presented in figure 2.

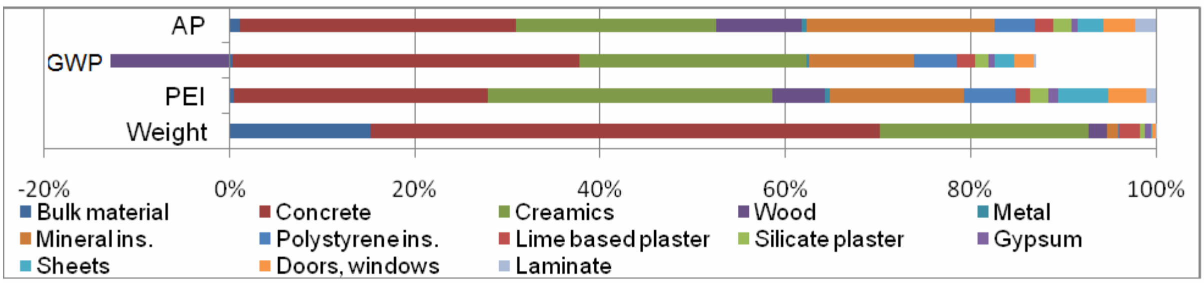

Figure 2: Contribution of building material groups to environmental indicators of house H1

In house H1 concrete was the material with the largest weight percentage (55%), while contribution of concrete materials on PEI reached 27.4%, on GWP 37.4% and on AP 29.7%.

The second heaviest were ceramic structures (bricks, tiles) with 22.5% of weight. However PEI of ceramics reached the highest value (30.7%), contribution to GWP reached 24.5% and contribution to AP reached 21.6%. On the other hand, thermal insulation with relatively light weight (polystyrene – 0.1%, mineral insulation – 1.1%) contributed to environmental indicators in substantial way: PEI (polystyrene – 5.6%, mineral insulation – 14.5%), GWP (polystyrene – 4.6%, mineral insulation – 11.4%) and AP (polystyrene – 4.3%, mineral insulation – 20.3%). Contribution of wood to GWP reached the negative value (-12.9%).

Percentage of contribution of the building materials to particular impact categories of house H2 is presented in figure 3.

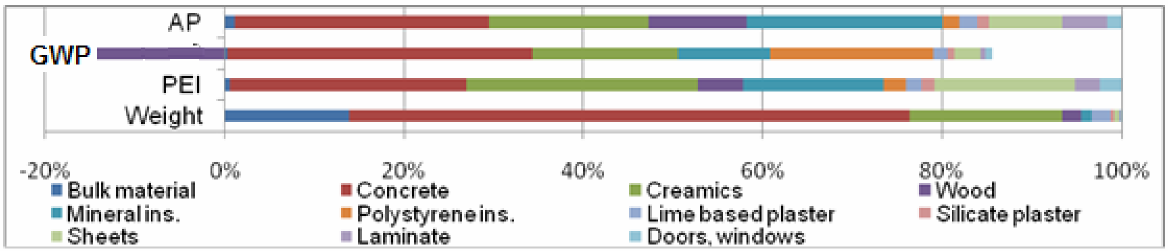

Figure 3: Contribution of building material groups to environmental indicators of house H2

Concrete materials of house H2 (figure 3) were materials with the highest percenage of weight (62.4%), PEI with 26.4%, GWP (34%) and AP (28.3%). Ceramics reached the second highest calculated weight (17.1%) and PEI (25.8%), the third highest GWP percentage (16.3%) and AP (17.8%). Polystyrene was responsible for 18.1% of GHG emissions and mineral insulation contributed to AP by 21.9%. The negative contribution of wood to GWP reached -14.4%.

Distribution of environmental indicators of building materials of house H3 are presented in figure 4.

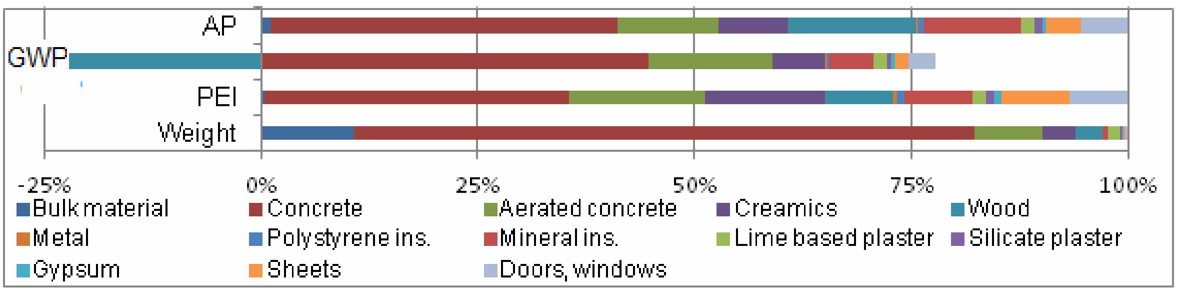

Figure 4: Contribution of building material groups to environmental indicators of house H3

As illustrated in figure 4, concrete was the heaviest (71.8% of total weight) and was also the one with highest PEI value (35.1%), GWP (44.5%) and AP (40.1%). For this house relatively large negative contribution to GWP (-22.3%) was calculated due to intensive use of wood products.

The share of particular environmental indicators of materials of house H4 is analyzed in figure 5.

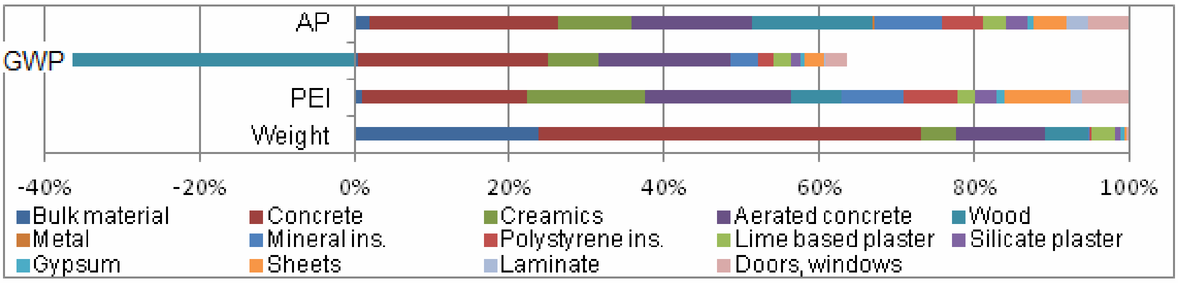

Figure 5: Contribution of building material groups to environmental indicators of house 4

Concrete of house H4 was evaluated as the heaviest (49.2% of weight). Concrete was also the material with the highest share of embodied energy (21.3%), embodied CO_2 emisions (24.5%) and SO_2 emissions (24.1%). A positive fact is the negative value of greenhouse gasses emission of wood materials of roof or celing, which reached -36.3% of total CO_2 emissions.

Percentage of particular impact categories for house H5 is presented in figure 6.

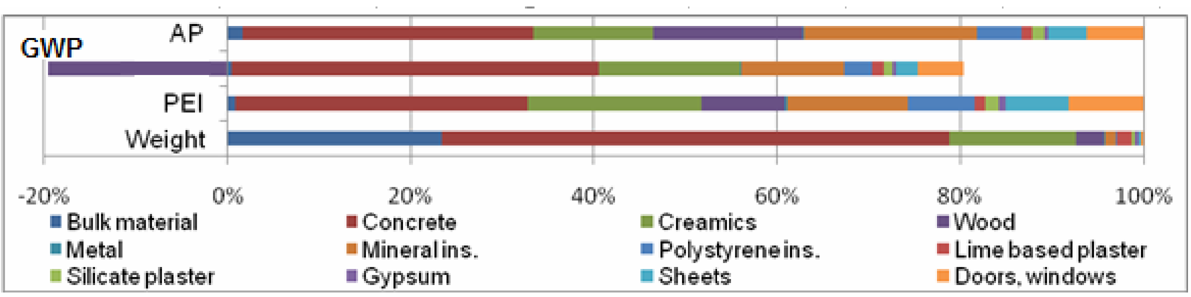

Figure 6: Contribution of building material groups to environmental indicators of house H5

As illustrated in figure 6, the heaviest materials of house H5 were concrete, bulk and ceramic materials with 55.3%, 23.5% and) 13.9% of weight ratio, respectively. The share of concrete on embodied energy reached 31.9%, followed with ceramics (19%). The highest amount of CO_2 emissions was calculated for concrete materials (40.1%) and ceramics (15.3%). Acidification reached the highest level in concrete (31.7%) followed by mineral thermal insulation (18.8%). The negative contribution of wood to GWP reached -19.6%.

3.4 Normalized environmental performance

Normalization of total values provides a more precise comparison of particular environmental parameters of various buildings. The total values of environmental performance for particular structures may reach high measure; however normalization per m2 of particular area or per m3 of volume offers a more relevant comparison of houses of different size, as presented in table 4.

Table 4: Normalized environmental profile

Normalized weight	H1	H2	H3	H4	H5
Build-up area (kg/m^2)	1644.3	1978.8	1911.9	1635.9	2039.1
Useful area (kg/m^2)	1952.9	2548.9	2891.0	2187.1	2637.6
Living area (kg/m^2)	2943.9	4738.1	4778.5	4018.1	4911.8
Build-up cubature (kg/m^3)	364.9	489.4	419.4	288.3	433.9
Normalized PEI	H1	H2	H3	H4	H5
Build-up area (MJ/m^2)	3765.2	3602.5	3259.2	3358.6	4474.1
Useful area (MJ/m^2)	4471.7	4640.4	4928.4	4490.3	5787.5
Living area (MJ/m^2)	6741.0	8625.9	8145.9	8249.4	10777.6
Build-up cubature (MJ/m^3)	835.6	890.9	714.9	591.9	952.0
Normalized GWP	H1	H2	H3	H4	H5
Build-up area (kg CO_2eq/m^2)	214.0	274.6	191.7	98.9	225.1
Useful area (kg CO_2eq/m^2)	254.1	353.7	289.9	132.2	291.2
Living area (kg CO_2eq/m^2)	383.1	657.5	479.2	242.8	542.2
Build-up cubature (kg CO_2eq/m^3)	47.5	67.9	42.1	17.4	47.9
Normalized AP	H1	H2	H3	H4	H5
Build-up area (kg SO_2eq/m^2)	1.068	1.158	1.018	0.961	1.427
Useful area (kg SO_2eq/m^2)	1.269	1.491	1.539	1.285	1.846
Living area (kg SO_2eq/m^2)	1.913	2.772	2.544	2.360	3.437
Build-up cubature (kg SO_2eq/m^3)	0.237	0.286	0.223	0.169	0.304

Analysis of normalized values of weight, PEI, GWP and AP presented in table 4 and their comparison to total values (table 3) reveals the more accurate comparison of buildings when using normalized values, because normalized results provide more relevant measure as it eliminates the size differences of buildings. E.g. in the case of normalization to useful area, the difference between the best and worst alternative reached 32.4% in the case of weight (H1-H5); 22.7% in the case of PEI (H1-H5), 62.6% for GWP (H4-H2) and 31.3% for AP (H1-H5).

4 Conclusion

The selection of suitable building materials is an important factor in building design which requires analysis of wide range of parameters, including environmental ones. In this paper environmental profile of 5 houses was presented with several findings, however they are difficult to be interpreted. The overall environmental impact of materials of underwork and vertical load bearing walls (concrete, ceramic brick etc.) is relatively negative as the total values of PEI, GWP or AP reached the high level due to large amount of used materials. However, also materials with relative low percentage of weight (e.g. thermal insulation) caused led to the negative environmental impacts on global warming or acidification. An important factor is the use of plant materials (wood in this case), which do not contribute to greenhouse gasses emissions and therefore may be one of the possible ways in fulfilling the sustainability strategies. The results of case study have proven that a further investigation in the branch of sustainable building is necessary in order to address such a negative impact of building industry.

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