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Process of Selection of Building Materials towards Sustainable Development

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Building industry belongs to one of the most polluting industries. Therefore, the minimization of energy requirements of buildings, as well as the reduction of emissions produced within the buildings life cycle has become a point of interest of many engineers, designers, architects or researchers. Every process in construction sector requires large amounts of energy, which mostly originate from fossil fuels, emits substantial amounts of CO_2 or SO_2 and produces waste or pollution. Existence of buildings is thus responsible for more than one third of green house gasses produced, as well as for consumption of about the same share of energy.
The selection of building materials used for construction of building is usually performed on the basis of technical and economical parameters. However, a question of environmental performance is increasingly taken into consideration with the principal aim of reaching sustainability, but is still not sufficient. As a matter of wide range of various parameters with different importance it is sometimes difficult to select the best-suited construction.
In this paper a selection of building materials to construct external walls with technical, as well as environmental criteria in mind using multi criteria selection is presented. 5 compositions of external walls made of aerated concrete blocks with thickness of 300 mm and 375 mm were included into evaluation. In 4 structures the thermal insulation material (2 types of mineral insulation or 2 types of polystyrene) was added. Multi criteria analysis was performed on the basis of assessors' preference as well as on the basis of their considerable importance. Evaluation included technical parameters, such as thickness of wall, weight of used material, quantity of layers; thermal-physical parameters (calculated U-value, surface temperature) and environmental parameters, which were calculated on the basis of available materials' database. Environmental assessment was focused on 3 parameters: embodied energy of materials expressed by amount of Primary Energy Intensity, amount of CO_2 emissions as Global Warming Potential and quantity of acidification gasses as Acidification Potential. Calculated values of environmental indicators were in range from 554.56 MJ/m^2 to 689.25 MJ/m^2 in the case of Primary Energy Intensity. Amount of calculated CO_2 emissions (Global Warming Potential) ranged from 49.26 kg CO_2eq/m^2 to 58.88 kg CO_2eq/m^2 and values of Acidification Potential were calculated in range from 0.1296 kg SO_2eq/m^2 to 0.2063 kg SO_2eq/m^2. Environmental performance was compared with conventional evaluation and the optimal construction from the evaluated external walls was chosen.

1. Introduction

In last few decades, as the construction sector grew rapidly, the questions of its unsustainability have been become discussed in various panels. However, the level of decrease of its negative impact is still

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not satisfactory and after food production the building sector belongs to the most polluting industries. It is responsible for production of almost 40 % of CO_2 (Guerra Santin et al., 2009, Desruelles, 2011) as well as for about the same share of energy consumed (Itard and Meijer, 2008). Several studies have been performed in order to minimize amount of operational energy disregarding the impact of building throughout their life cycle (Monteiro and Freire, 2012) or with special stress on construction or use stages (Hacker et al., 2008, Monahan and Powell, 2011). The Life Cycle Assessment studies usually don't include every stage, but are performed within cradle to gate boundaries. Even European Commission in the Directive 2010/31/EU has introduced some regulations aimed at the reducing of negative influence of building industry. Still, its targets are focused on the reduction of energy consumption by 20 %, decrease of GHG emissions by 20 %, and on increase of the share of renewable resources of energy to 20 % and thus are concerned with the use phase mostly. In order to reduce the environmental burdens concerned with building besides operation of building also other processes should be included into evaluation.
Results of various studies (Eštoková et al., 2011, De Benedetto and Klemeš, 2008) indicated that broad optimum design does not exist and evaluation of individual project is necessary. Selection of material composition from the early design stages of building design influences structures properties, future operation as well as the environmental performance of building material, component or the whole building, therefore it shouldn't be underrated. In this paper a design of exterior walls regards the principles of sustainable development is illustrated through the multi-criteria approach. The technical, thermal-physical and environmental performances were taken into consideration.

2. Material and methods

2.1 Description of assessed walls

Exterior walls have many important functions in the building envelope. They not only define the indoor space or separate interior and exterior, but also transfer the loads from other structures, protect against fire, heat losses or fulfil acoustic insulation. 5 walls were designed and assessed. First alternative included single layer masonry wall (PB1) with use of 375 mm thick aerated concrete block, indoor layer of 10 mm thick lime-cement plaster and 15 mm thick layer of external plaster with added perlite to improve the insulation value. In other structures (PB2-5) the 300 mm thick aerated concrete block was used. 375 mm thick block does not require additional thermal insulation. However, the use of thinner blocks requests the application of thermal insulation layers to meet the thermal-physical requirements. In PB2 50 mm of glass wool is used, in PB3 the same thickness of rock wool is applied. Polystyrene (50 mm thick layer) is used in PB4 (EPS-F) and in PB5 (EPS-F with graphite). In insulated walls (PB2-5) 10 mm thick lime-cement plaster is used for internal rendering, 3 mm of adhesive mortar is used to apply the thermal insulation material and 5 mm of silicate plaster with glass-textile mash for the outdoor finishing. Design parameters for calculation of thermal-physical properties (e.g. ρ-bulk density, λ-coefficient of heat conductivity, μ- diffusion coefficient) of principal materials are presented in Table 1.

Table 1: Main design parameters of principal materials

Wall	Aerated concrete block				Thermal insulation layer			
	Thickness mm	ρ kg/m^3	λ W/mK	μ -	Thickness mm	ρ kg/m^3	λ W/mK	μ -
PB1	375	400	0.12	7	-	-	-	-
PB2	300	400	0.12	7	GW, 50	32	0.032	1
PB3	300	400	0.12	7	RW, 50	150	0.039	2
PB4	300	400	0.12	7	EPS-F, 50	17	0.04	60
PB5	300	400	0.12	7	EPS-g, 50	16	0.031	60

GW-glass wool, RW-rock wool, EPS-F-expanded polystyrene, EPS-g- EPS with graphite

2.2 Evaluation method

Conventional assessment included evaluation of technical and thermal-physical parameters, such as heat transfer coefficient – U-value (W/m^{2}K), surface temperature – Θ_{si} (°C), phase shift – ϕ (h), amount of layers (-), total thickness of composition (mm) as well as weight of structures (kg/m^2). Environmental evaluation included evaluation structures' amount of embodied energy – PEI (MJ/m^2), global warming potential – GWP (kg CO_2eq/m^2) and acidification potential – AP (kg SO_2eq/m^2). Environmental performance calculated in the dependence on the quantity of used materials of external walls was evaluated using specific building materials database (Waltjen et al., 2009). As large amount of various parameters is taken into consideration a multi criteria assessment was performed in order to select the best suited structure. Importance of particular parameters included 2 alternatives. In the first alternative the equal weights were used. In the second one the weight criteria were set by Fuller triangle method (Fiala et al., 1997).

3. Results

3.1 Evaluation of particular parameters

Matrix of structures and respective properties calculated are listed in Table 2.

Table 2: Calculated properties of assessed exterior walls

Wall	Layers	Thickness	Weight	U	Θsi	ϕ	PEI	GWP	AP
	-	mm	kg/m^2	W/m^{2}K	°C	h	MJ/m^2	kg CO_2eq/m^2	kg SO_2eq/m^2
PB1	3	400	173.30	0.288	17.71	15.0	554.56	54.53	0.1349
PB2	5	368	150.01	0.235	18.10	13.5	594.18	50.20	0.1296
PB3	5	368	155.91	0.252	17.98	13.8	689.25	58.88	0.2063
PB4	5	368	149.26	0.254	17.78	13.4	598.23	49.43	0.1459
PB5	5	368	149.21	0.232	17.97	13.5	593.30	49.26	0.1448

As illustrated in Table 2, the calculated values of 9 assessed indicators were in a wide range. Building a masonry structure or applying of thermal insulation is a process which requires skilled works and thus is labor intensive. Therefore, if the number of layers is reduced, the less time for build-up and less work is required. In wall PB1 single layer masonry without thermal insulation was used, therefore only 3 layers were used for this construction. Considering the thickness of structure, the lower thickness of wall provides more indoor space. In structures PB2-5 the thickness was lower (368 mm) comparing to wall PB1 with 400 mm. Weight of wall influences the loading supported by foundations. Higher weight of material used involves more material of foundations to transfer load, but on the other hand improves some thermal technical properties (thermal stabilization). For this assessment the lighter structure was considered to be more favorable. Wall PB5 with weight of 149.21 kg/m^2 reached the best value.
Thermal technical assessment included evaluation of thermal protection – the U-value. The lower U-value provides better insulation and the lowest values was calculated in structure 0.232 W/m^{2}K. Surface temperature is the issue of perceived thermal comfort. Users feel more comfortable in the areas with warmer walls. The highest surface temperature was calculated in wall PB2 and reached 18.10 °C. Phase shift represents the measure of thermal stabilization and expresses the time of transfer of temperature change from exterior to interior. The higher value supplies better stabilization. In structure PB1 the highest value of phase shift was reached (15.0 h).
Environmental evaluation included amount of primary energy (embodied energy). The lower PEI calculated the less energy within cradle to gate is concerned with the materials of structures. The lowest PEI was calculated for PB1 with 554.56 MJ/m^2. The lowest amount of greenhouse gasses emissions (least negative impact on global warming) was calculated for structure PB5 and reached 49.26 kg CO_2eq/m^2. Acidification potential was also assessed. The lowest quantity of SO_2 emissions was reached in construction PB2 (AP=0.1296 kg SO_2eq/m^2).
As a result of particular assessment of parameters it is difficult to rate the most suitable structure, as the lowest values of few parameters were reached in 3 different structures (PB1, PB2 and PB5).

3.2 Multi criteria evaluation

The multi criteria analysis (MCA) was performed to provide the evaluation of several parameters as one integrated assessment (Korviny, 2003). To compare the result using different calculations four methods were used in this study: CDA (Concordance Discordance Analysis), IPA (Ideal Point Analysis), WSA (Weighted Sum Approach) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Calculated values of evaluated parameters presented in Table 2 served as input for the multi criteria analysis. Setting of importance of particular parameters is an important factor which may influence the final results (Voelker and Kornadt, 2012). As presented by Alzaed and Boussabaine (2012), it is necessary to understand the user's needs to in order to integrate their needs into design or evaluation. In this study 2 alternatives of weights were considered. In the first alternative the importance of indicators was equal, while in the second alternative the weights were calculated using assessors' attitude by comparing of each parameter with each other using Fuller method (Korviny, 2003, Fiala et al., 1997). Importance of particular indicators is presented in Table 3.

Table 3: Weights of assessed parameters of multi criteria analysis

Parameter	Layers	Thickness	Weight	U	Θsi	ϕ	PEI	GWP	AP
max=1,min=0	0	0	0	0	1	1	0	0	0
Alternative 1 (%)	11,11	11,11	11,11	11,11	11,11	11,11	11,11	11,11	11,11
Alternative 2 (%)	2,98	16,53	2,98	17,89	8,40	4,34	19,24	16,53	11,11

Multi criteria evaluation of alternative 1 (equal importance of particular indicators) is presented in Table 4, while multi criteria assessment (alternative 2) with importance of indicators determined using Fuller method is presented in Table 5.

Table 4: Multi criteria assessment of walls (alternative 1)

Rank	CDA		IPA		WSA		TOPSIS	
1	PB5	2,4097	PB2	0,2684	PB2	0,7316	PB1	0,568
2	PB2	2,4758	PB5	0,3062	PB5	0,6938	PB2	0,5572
3	PB4	4,9316	PB4	0,4188	PB4	0,5812	PB5	0,5572
4	PB3	6,2048	PB1	0,5129	PB1	0,4871	PB4	0,5267
5	PB1	6,2222	PB3	0,6326	PB3	0,3674	PB3	0,338

As presented in Table 4, the multi criteria assessment is sensitive on method selection. With the equal importance of parameters the structure PB5 (300 mm aerated concrete block + 50 mm of EPS with graphite) was marked as the best suited using CDA method. When using IPA and WSA method the wall PB2 (300 mm aerated concrete block + 50 mm of glass wool) reached the top rank and PB1 was evaluated as the best one applying Topsis method.

Alternative 2 of multi criteria evaluation of exterior walls with weight calculated upon assessors'preference is presented in Table 5.

When applying more realistic importance of parameters – weights (Voelker and Kornadt, 2012) upon assessors' preference with the highest stress on amount of primary energy, U-value, thickness and global warming potential two structures were evaluated as the best suited. When using CDA and Topsis method the structure PB5 reached the optimal values. However, wall PB2 was rated as the best suited when using IPA or WSA method.

Table 5: Multi criteria assessment of walls (alternative 2)

Rank	CDA		IPA		WSA		TOPSIS	
1	PB5	1,1747	PB2	0,1537	PB2	0,8463	PB5	0,8036
2	PB2	1,5592	PB5	0,1758	PB5	0,8242	PB2	0,7992
3	PB4	3,3693	PB4	0,3013	PB4	0,6987	PB4	0,7197
4	PB3	5,9585	PB1	0,5561	PB1	0,4439	PB1	0,4966
5	PB1	5,9672	PB3	0,6292	PB3	0,3708	PB3	0,3843

4. Conclusion

Selection of best suited building material and its incorporation into building structure is a complicated process which should consider many design parameters or properties. When designing any structure including exterior wall a complex approach with technical, physical as well as environmental parameters in mind is necessary. Summarising the results of design and assessment one should specify the needs, preferences or the required importance of assessed indicators, as this is the key factor which can influence the results of evaluation. Adding of environmental indicators to evaluation of conventional parameters can widen the design criteria and may lead to more accurate selection of material compositions also considering selected environmental criteria.

In this study only several materials and a few possible compositions with the use of limited design criteria were included. In spite of a few assessed alternatives the results have proven, that implementation of environmental assessment may be helpful in designing of structures with lower environmental impact. From assessed scenarios considered in this study the structures with 300 mm thick aerated concrete block and with use of glass wool insulation or with use of EPS with graphite insulation (50 mm thick) were rated as the best suited in this particular case.

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