CHEMICAL ENGINEERING TRANSACTIONS Volume 25, 2011
Editors Jiří Jaromír Klemeš, Petar Sabev Varbanov, Hon Loong Lam

DOI: 10.3303/CET1125109

Minimization of CO_2 Emissions and Primal Energy by Building Materials' Environmental Evaluation and Optimization

Adriana Eštoková*, Milan Porhinčák, Róbert Ružbacký
Building and Environmental Institute, Civil Engineering Faculty, Technical University of Košice, Vysokoškolská 4, 04200 Košice, Slovak Republic
adriana.estokova@tuke.sk

Building industry has leading position in deterioration of environment. Therefore environmental assessment of building materials is very important. Life Cycle Assessment is the most complex method for quantifying of environmental impact and performing optimization. A single-family residential house was selected for evaluation and optimization of building materials, as presented in this paper. Building materials were divided into 10 groups of structures on the basis of calculation tool of Createrra. Contribution of building and particular structures in terms of used materials was enumerated. The highest contribution to global warming (GWP = 17770.5 kg CO_2eq), acidification (AP = 57.2 kg SO_2eq) and the highest consumption of primal energy (PEI = 153 350.4 MJ) was calculated for materials used in foundations. Some structures were selected for further material optimization to minimize their negative impact. It was proven that the proper selection of materials can lead to minimizing of the negative impact on environment by reducing energy consumption and CO_2 and SO_2 emissions.

1. Introduction

Rising number of inhabitants has become unsustainable and led to depletion of natural resources and other harmful effect on environment. Pollution represents an enormous issue which causes the serious problems such as global warming, ozone layer depletion, acidification and other negative effects. Building industry has leading position in this deterioration (Scholes, 2003) by natural sources' depletion, energy consumption, land occupation etc. In highly developed countries building are responsible for up to 40 % of total energy consumption in the industry and are accounted for more than 1/3 of electricity consumption (U.S. Department of Energy, 2008). Several organizations (U.S. Department of Energy, 2007; European Environmental Agency, 2006) proclaimed that construction, operation and demolition emit at about 40 % of CO_2.
A more intensive approach, where quantifying of environmental criteria such as weight, recycling possibility, waste production, primal energy consumption, CO_2 or SO_2 emissions is especially important (Tan and Foo, 2009). One of the most reputable methods for environmental assessment of building materials is Life Cycle Assessment – LCA (De Benedetto and Klemes, 2008). This paper illustrates the environmental assessment of building materials of selected building. Approach of optimization of material selection is also implied.

Please cite this article as: Estokova A., Porhincak M. and Ruzbacky R., 2011, Minimization of co2 emissions and primal energy by building materials' environmental evaluation and optimization, Chemical Engineering Transactions, 25, 653-658
DOI: 10.3303/CET1125109

2. Material & methods

2.1 Characteristics of the evaluated building

The one storey house with 2 bedrooms, living room, bathroom and toilet was selected for evaluation process. Build up area of house is 178 m^2, of which 170.5 m^2 belongs to house and 7.5 m^2 is storm lobby. Useful area is 129.9 m^2, floorage is 84.3 m^2 and total capacity is 725 m^3. More detailed information is presented by Ruzbacky (2010).

2.2 Description of the structures

Foundations are made of plain concrete; XPS is used to eliminate heat bridges. Vertical load-bearing and partitioning structures are made of aerated concrete blocks. Horizontal load-bearing constructions (beams of ceiling) are made of technically dried wood, while shuttering is made of OSB boards. Material of bond beams and capping is reinforced concrete. Wood beams create the framework of the roof. Roof weatherproofing is secured by ceramic roof tiles. Surface of floors is made of wooden panels and ceramic tiles. Plastering of external walls is made of silicate plaster, while inner plastering is made of lime-cement. Plasterboard is used in the lower ceiling. Thermal insulation of external walls is secured by material itself. However, 50 mm of glass wool is used to improve insulation value. Mineral wool is used in attic. Polystyrene is applied in the underwork. Windows are double glazed filled with argon, frames are made of plastic.

2.3 Assessment method

Building materials were evaluated by modified assessment tool by Createrra, which enables quantifying of Primal Energy Intensity PEI, Global Warming Potential GWP and Acidification Potential AP of structures. Structures of building are sorted into 10 groups. Volumes and areas of used material serves as program input. The calculation is based on the specific database of building materials (Waltjen, 1999). Values of GWP don't include the data from the last phase of life cycle. Kierulf (2008) presented, that some natural materials have the negative contribution to GWP, as they consume the CO_2 during their growth and as long as they are not combusted, no emissions of CO_2 are emitted (Waltjen, 1999). However, some sources (Hammond and Jones, 2008) state zero or positive values of GWP.

3. Results

3.1 Environmental assessment of original building design

Results of environmental assessment are illustrated in Table 1. The highest weight was calculated for foundations (176592.24 kg) as a result of high density of materials. PEI is the highest in the same structure (PEI=153350.37 MJ), fairly high value of PEI is for materials of vertical load-bearing structures (PEI=108459.86 MJ) and materials of thermal insulation (PEI=101734.23 MJ). High emissions of CO_2 are related to energy intensive processes (Hammond, 2008), therefore the biggest contribution to GWP have materials of thermal insulation (47665.82 kg CO_2eq), foundations (17770.53 kg CO_2eq) and vertical load-bearing structures (10555.74 kg CO_2eq). Some constructions have negative contribution to GWP, e.g. materials of ceiling (-7348.00 kg CO_2eq) and roof (-4284.37 kg CO_2eq) by reducing greenhouse effect due to considerable amount of wood.

The negative effect of acidification is the most noticeable for materials of thermal insulation (233.01 kg SO_2eq) and foundations (57.1518 kg SO_2eq).

Table 1: Environmental impact of materials of structures in original building design

	Construction	PEI [MJ]	GWP [kg CO_2eq]	AP [kg SO_2eq]
1.	Foundation	153350.38	17770.54	57.15
2.	Thermal insulation of foundation	4031.82	135.97	0.83
3.	Vertical load-bearing structures	108459.87	10555.74	29.13
4.	Partitioning structures	16603.09	1597.56	3.86
5.	Ceiling	29683.59	-7348.00	18.47
6.	Roof	52135.63	-4284.37	13.22
7.	Thermal insulation	101734.24	47665.83	233.02
8.	Facade	12194.03	657.27	3.51
9.	Surfaces	49126.58	2076.03	13.79
10.	Doors and windows	2421.69	110.39	0.68
	Total	529740.91	68936.96	373.66

3.2 Optimization of constructional design

Materials of particular structures were alternated and new evaluation was calculated (table 2). As a matter of selection of constructional system only marginal optimization of foundation is available. Polymeric foil of original damp proof course was compared with EPDM rubber. It is difficult to choose more suitable material as some indicators are more favorable for polymeric foil (GWP, AP) while PEI is lower for EPDM. Originally designed materials of load-bearing (aerated concrete, 375 mm thick), which was compared to other materials, such as sand-lime bricks, perforated ceramic bricks, reinforced concrete and expanded clay concrete seemed to be the most suitable material. Comparison of partitioning walls was done with similar materials and with the same results than optimization of load-bearing wall. Construction of ceiling was originally made of technically dried wood and OSB. Materials of beams were changed for air-dried wood and laminated joints, and sheathing was alternated with MDF and air-dried wood. Air-dried wood appears to be most suitable material for both, load-bearing and sheathing structures of ceiling. Materials similar to ceiling were used for roofs beams and sheathing, therefore similar result of optimization were calculated. Roof covering designed of ceramic clay was compared to concrete, aluminum sheet, galvanized sheet, copper sheet etc. Less negative effect was calculated for concrete (the lowest values of PEI, GWP and AP). Surfaces of walls and ceiling were originally designed of lime-cement plaster. Alternated materials were clay, gypsum, lime-gypsum, trass, lime and plasterboard. The less negative effect was estimated when clay plaster was used.

Table 2: Optimization of materials of particular structures

		PEI [MJ]	GWP[kg CO_2eq]	AP[kgSO_2eq]
Damp proof course	Polymeric foil	28835.73	654.59	4.10
	EPDM	278251.12	817.52	4.80
Load bearing walls	Lime sand blocks	90760.44	11318.11	17.25
	Aerated concrete	81945.36	7884.86	19.06
	Perforated brick	118630.20	8385.11	26.20
	Reinforced concrete	262126.29	25776.88	98.17
	Keramzite concrete	166794.28	32015.86	221.78
Partitioning structures	Lime sand blocks	18389.11	2293.18	3.49
	Aerated concrete	16603.07	1597.56	3.86
	Perforated brick	24035.85	1698.92	5.31
Ceiling	Glued wood beams	22827.17	-3574.55	9.68
	Technically dried wood	8486.40	-4648.80	5.02
	Aid dried wood	6368.54	-4747.77	4.18
Ceiling-shuttering	OSB	21192.81	-2655.92	13.71
	Wood	5546.95	-2811.38	3.15
	MDF	31979.39	-2794.84	11.10
Roof	Concrete shingle	16863.98	1865.40	4.43
	Ceramic shingle	37676.09	1648.71	5.77
	Anodized Al sheet	82435.64	5876.01	28.23
	Coated Al sheet	82435.64	5882.61	27.96
	Galvanized sheet	47581.55	2096.17	14.66
	Titanium-zinc sheet	46847.00	2921.05	42.77
	Copper sheet	145708.29	8041.10	245.05
Surfaces	Clay	1600.60	-200.08	0.58
	Gypsum	8703.92	435.20	1.53
	Lime-gypsum	8091.92	584.79	17.00
	Lime-cement	7343.93	720.27	2.64
	Trass-lime	7286.39	750.61	1.90
	Lime	6695.32	340.00	1.18
	Plasterboard	9648.06	451.28	1.47
Thermal insulation	Glass wool	27493.50	1247.70	0.73
	Rock wool	27807.70	1957.28	12.53
	Polystyrene EPS F	14394.63	489.56	3.15
	Polystyrene EPS	11995.53	407.97	2.63
	Hemp with PE fibre	7574.84	-32.39	1.31
	Hemp without PE fibre	6600.58	-91.82	1.06
	Flax with PE fibre	9255.43	88.66	2.12
	Flax without PE fibre	8281.18	29.47	1.88
	Straw	211.09	-1925.78	no data

Materials of thermal insulation were optimized on basis of corresponding U-value (coefficient of heat transmission). Original core material (aerated concrete, 375 mm thick) remained unchanged; however, materials of thermal insulation originally designed of 50 mm thick layer of glass wool were alternated. U-value for this construction (S1) calculated by program Teplo (2009) is approximately 0.243 W/m^2K, including plastering, which fulfills requirements of Slovak technical standard STN 730540 for external walls, which should not exceed 0.32 W/m^2K.
Thicknesses of alternated insulation materials were calculated to retain the U-value similar to U of original scenario (S1). Composition of scenarios S1-S4 consisted of: lime-cement plaster (10 mm), aerated concrete (375 mm), adhesive mortar (3 mm), thermal insulation (50 mm) and silicate plaster with glass-textile mash (5 mm). External plastering in scenarios with natural fibers (S5-S9) was replaced with wood paneling.
As a result of optimization, the most suitable material for thermal insulation appears to be hemp without PE fiber, even thought the values of PEI and GWP when straw used reached lower values. Input data for straw are however from different source (Culakova, 2010), miss AP values and are in dependence on bulk density of straw bales used.

3.3 Comparison of original and optimized building design

After optimization of structures a new assessment was made. The reduction of potentials was reached for 4 evaluated structures as it is shown in table 4, however the original design of remaining structures appeared to suitable.

Table 4: Comparison of PEI, GWP and AP in original and optimized building (A. Ceiling, B. Roof, C. Thermal ins., D. Surfaces)

	Original	Optimized	Original	Optimized	Original	Optimized
	PEI [MJ]		GWP [kg CO_2eq]		AP [kg SO_2eq]	
A.	29683.58	11919.86	-7348.00	-7602.43	18.46	7.06
B.	52135.63	31323.52	-4284.37	-4067.68	13.22	11.88
C.	101734.23	80841.31	47665.82	46326.30	233.01	233.34
D.	49126.58	43383.25	2076.02	1155.67	13.78	11.72

Fox example, maximum PEI reduction was reached for materials of thermal insulation (33175.48 MJ, what represents reduction by 41%). The highest percentage of CO_2 emissions reduction (44 %) was reached by optimizing materials of surfaces, what equals to 920.35 kg CO_2eq. AP was cut-down by 61.7% by alternating the materials of ceiling, what represents reduction by 11.4 kg SO_2eq. Final comparison of original and optimized building design summarized in table 5.

Table 5: Final comparison of original and optimized buildings

	PEI [MJ]	GWP [kg CO_2eq]	AP [kg SO_2eq]
Original building	529740.91	68936.96	373.66
Optimized building	464528.83	66639.35	359.19
Reduction	65212.08	2297.61	14.47
Reduction [%]	12.3	3.3	3.9

4. Conclusion

The main purpose of optimization was to illustrate minimizing the negative effect of building materials. The alternative building materials were chosen in way to ensure the similar technical attributes. As the final comparison shows, the optimized building consumes less primal energy by 65212.08 MJ, what means cut-down by 12.3%. Emissions of CO_2 were reduced by 3.3 %, what represents reduction of 2297.61 kg CO_2eq. Even emissions of SO_2 were brought down in optimized building by 3.9 % (14.47 kg SO_2eq). Optimization has proven that by a proper choice of building material it is possible to reduce the negative environmental effects. In spite of relatively small changes in material basis of structures the reduction of PEI, as well as GWP and AP was reached.

Acknowledgment

This research has been supported by Slovak Grant Agency for Science (Grant No. 2/0166/11).

References

De Benedetto L. and Klemes J., 2008, LCA as environmental assessment tool in waste to energy and contribution to occupational health and safety, Chemical Engineering Transactions, 13, 343-350.

Culakova M., 2010, Environmental-Friendly Straw Bale House, Building Materials, 6, 14-16. (in Slovak)

European Environmental Agency, 2006, EU greenhouse gas emissions increase for second year in a row <www.eea.europa.eu/pressroom/newsreleases/GHG2006-en> accessed 15.12.2010 .

Hammond G.P. and Jones C.I., 2008, Embodied energy and carbon in construction materials, Proc. Institution of Civil Engineers: Energy, 161, 87-98.

Kierulf B., 2007, Ecological build-up, House and flat 2, 1-7. (In Slovak)

Ruzbacky R., 2010, Environmental Assessment of Selected Building in Terms of Building Materials, MSc Dissertation, Technical University of Kosice, Kosice, Slovakia. (in Slovak)

Scholes R., 2003, Stories from the Stone Age. Beyond Productions in association with S4C and S4C International, Australian Broadcasting Corporation.

Teplo 2009, Svoboda software, software group Building Physics 2009 (in Czech).

Tan R.R. and Foo D.C., 2009, Recent Trends in Pinch Analysis for Carbon Emissions and Energy Footprint Problems, Chemical Engineering Transactions, 18, 249-254.

U.S. Department of Energy, 2007, Buildings Energy Databook 2006, US Department of Energy and Annual Energy Review 2007. DOE/EIA-0384 (2007).

U.S. Department of Energy, 2009, Emissions of Greenhouse Gases Report. DOE/EIA-0573 <www.eia.doe.gov/oiaf/1605/ggrpt/index.htm> accessed 11.12.2010 .

Waltjen T., 1999, Deatils for Passive Houses. A Catalogue of Ecologically Rated Constructions. Springer Verlag, Vienna, Austria, ISBN 978-3-211-29763-6.