CHEMICAL ENGINEERING TRANSACTIONS

VOL. 39, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Peng Yen Liew, Jun Yow Yong

ISBN 978-88-95608-30-3; **ISSN** 2283-9216

DOI: 10.3303/CET1439101

Environmental Analysis of Materials Used for Building Foundation

Marcela Ondova*, Adriana Estokova

Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Vysokoškolska 4, Košice, Slovakia
marcela.ondova@tuke.sk

Currently is worldwide a strong and growing interest in the environmental performance as well as interest in evaluating of building material in terms of the sustainable construction.
This paper is aimed at the evaluation of materials used for building foundation of 4 residential buildings in the Slovak Republic in terms of its primary energy intensity (PEI), global warming potential (GWP) and acidification potential (AP). Foundation of houses contributes to total environmental impact of whole building by 22.7, 10.3 and 8.5 % in average for GWP, PEI and AP. Concluding the results, GWP values ranged from 0.07 to 0.12 kg CO_2eq/kg; PEI varied from 0.0.87 to 1.39 MJ/kg and AP from 0.00025 to 0.00036 kg SO_2eq/kg with average values of 0.091 kg CO_2eq/kg, 1.17 MJ/kg and 0.000295 kg SO_2eq/kg for GWP, PEI and AP, respectively. The calculated values were normalized not also to total weight of used foundation materials but to floor area and cubature as well.

1. Introduction

Achieving sustainability in architecture and construction is the goal emphasized more these days. Building construction has important role in sustainable development; especially due that constructed environment has great influence on life quality, comfort, security and health (Zabihi et al., 2012). It is well known that the construction, maintenance and updating of constructed environment have potential effects on environment (Junak and Stevulova, 2013), and buildings consume most of unrecoverable resources and create great amount of waste (Junak and Stevulova, 2011), and buildings create half of the total carbon dioxide (Mohammad, 2013). The increased numbers of the world population and carbon emission that leads to global warming must be addressed through sustainable approach and innovative techniques (Estokova et al., 2011). It is estimated that buildings in the countries of the European Union consume approximately 50 % of the total energy use and this consumption can result in almost 50 % of the CO_2 eq emissions released to the atmosphere over their life cycles (Vilcekova et al., 2013).
A strong emphasis of sustainability needs to be demonstrated through creating economical buildings that increase life quality while reducing social, economic and environmental effects (Kamar et al., 2010). However, minimization of the negative impact of building sector requires not only the regulation of the usage stage, but should also include other phases as extraction of raw materials, production of building products, erection of building, demolition etc. (Ramesh et al., 2010). Although the operation of buildings is stage with the highest negative impact on environment (Dodooa et al., 2010), in current buildings also other phases have significant environmental impact, especially as a result of use of high quantity of harmful materials used for building structures (Lia et al., 2013).
Life cycle assessment (LCA) of buildings is essential for understanding of construction impact on the environment. It is vital to include all phases of the life cycle of buildings: from material extraction, manufacturing and construction; building operations and the end-of-life stage where the building is demolished and reused or discarded. Because of an LCA presents an accurate estimate of the quantities and timing of environmental impacts, it provides a solid basis for identifying the benefits of changes in the

Please cite this article as: Ondova M., Estokova A., 2014, Environmental analysis of materials used for building foundation, Chemical Engineering Transactions, 39, 601-606 DOI:10.3303/CET1439101

Table 1: Configuration of assessed houses

Configuration	House 1	House 2	House 3	House 4
Total build-up area [m^2]	162.3	192.4	158.7	148.9
Calculated build-up area [m^2]	149.7	185.5	110.3	112.5
Total useful area [m^2]	394.6	468.6	168.6	182.4
Calculated useful area [m^2]	316.6	468.6	147.4	164.6
Living area [m^2]	126.3	235.8	114.7	87.0
Build-up [m^2]	398.4	518.7	220.6	220.2
Converted volume [m^3]	968.4	2 393	612.5	611.6
Heated area [m^2]	234.2	435.0	138.6	131.7
Heated volume [m^3]	539.1	1 131	530.0	507.0

construction of a building or its operation. Results of research have proven that generalized optimal design does not exist and precise analysis of single projects is necessary (De Benedetto and Klemeš, 2008). However, LCA is the most comprehensive approach to determining the environmental life cycle impacts of a building and can be used as a tool of the assessment of alternatives to make design decisions that would result in lower environmental impacts (Estokova et al., 2012).

The objective of this study was to analyse the embodied energy (primary energy intensity - PEI), embodied CO_2 (global warming potential - GWP) and SO_2 emissions (acidification potential - AP) of building foundations materials of selected family houses and their share on the overall building environmental profile.

2. Materials and methods

2.1 Description of evaluated houses

Four various buildings (one wooden and three masonry) were selected for evaluating of environmental parameters of building foundation. Purposeful space configuration of houses is presented in Table 1.

Description of assessed houses is as follows:

House 1 is a new wooden house with three floors and residential attic which is set onto masonry basement located in the countryside.

Construction and technical solutions of building foundations*:* Foundation of the house is based on the foundation strips of bulk concrete B10, which is interlaced with quarry aggregates up to 30 % by volume. The width is designed of 500 mm below the proposed cladding walls, 400 mm below the terrace and outdoor stairs. Columns foot of winter garden have dimensions of 600 × 600 mm and height of 1,300 mm. The thickness of the underlying concrete floor is 0.15 m of the concrete class B10 reinforced longitudinal in the place of partitions.

House 2 is a masonry townhouse located in the central urban area of the city in the historic conservation site. The townhouse is under reconstruction and the environmental evaluation considers the new material composition design.

Construction and technical solutions of building foundations: New foundations of the house of concrete class C25/30 are proposed under the newly designed vertical structure in the rear of the building. Base gap is proposed to non-freezing depth. The base concrete at the rear of the building is reinforced with steel mesh and a rod with a diameter of 6 mm and a distance of mesh 120/120 mm. Insulation of the foundation strip along its whole height is through insulation with thickness of 50 mm film NOPA.

House 3 is a new-built masonry house designed as an individually situated object consisting of ground floor and non-residential attic with roof span 22°. The building is equipped with a moderately steep terrain in the construction of houses.

Construction and technical solutions of building foundations: Foundation structures are designed as monolithic reinforced belts with a width of 600 and 500 mm and a height of 500 mm. They are designed from the concrete B20. Depth of foundation is 1.1 m below the level of modified terrain. Monolithic reinforced concrete strip will be added using shuttering blocks widths of 400 and 300 mm in two rows. The base plate is designed of unreinforced concrete class B15 with a thickness of 150 mm. Under the plate and strip is designed compacted gravel sand sub-base with a thickness of 150 mm.

House 4 is a re-built old masonry house. It is a two-storey, basement family house suitable in size for 4-5 residents. The house is covered by hipped roof.

Construction and technical solutions of building foundations: The building is based on the original foundation strips of bulk concrete C16/20. Foundation strips (width 700 mm) are based in the non-freezing depth. The base concrete is of bulk concrete C16/20 and is complemented with reinforced mesh

150/150 mm. Under the plate and strip is designed compacted sand gravel sub-base with a thickness of 250 mm. When reconstructing it was applied to the base plate reinforced concrete insulated XPS. As part of the rebuilding the reinforced concrete insulated with extruded polystyrene (XPS) on the base plate was used.

2.2 Methodology

Environmental evaluation of houses foundations was based on the calculation of environmental impacts of foundation building materials used in four selected buildings. Environmental impact was expressed in terms of three environmental indicators: embodied energy (PEI – MJ), embodied CO_2 emissions (GWP – kg CO_2eq) and embodied SO_2 emissions (AP – kg SO_2eq). The environmental indicators have been calculated according to Eq(1):

$$EI = \sum_i m_i . E_i \tag{1}$$

where m_i represents weight of particular material in house foundation and E_i is the unit environmental indicator per 1 kg of building material.

Quantitative description of used materials was extracted from project documentation (volumes and areas of used materials). Used unit environmental indicators per 1 kg of building material consider cradle to gate boundaries (Waltjen, 2008). The origin of data for calculation of environmental performance of used materials was from broadly used IBO database (Porhincak and Estokova, 2013). Subsequently, the results were compared within evaluated objects. The results of building foundation environmental impacts were compared with overall environmental profiles of the whole building, including materials for the construction of vertical load bearing walls, partition walls, ceiling, roof, thermal insulation, surfaces and door & windows to demonstrate their percentage share in the overall assessment. For better comparability, the total environmental indicators were converted to reference values by dividing of floor area, heated volume and total weight of materials in hose foundation.

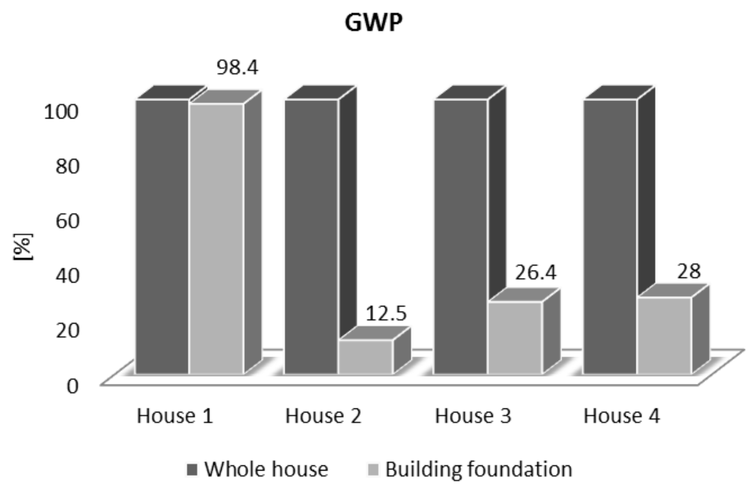

Figure 1: Contribution of houses foundation to GWP of whole building

3. Results and discussion

Calculated values of primary energy (PEI), global warming potential (GWP) and acidification potential (AP) as well as total material mass of foundation materials of four evaluated houses are presented in Table 2.

PEI values have been calculated in range of $1.22 \cdot 10^5$ to $2.50 \cdot 10^5$ MJ with average value of $1.99 \text{x} 10^5$ MJ, while GWP ranged from $0.10 \cdot 10^5$ to $0.24 \cdot 10^5$ kg CO_2 eq with average value of $0.16 \cdot 10^5$ kg CO_2 eq. Calculated AP values have been lower by several orders of magnitude (35.27 - 70.96 kg SO_2 eq).

The calculated values of foundations environmental indicators have been compared to the whole environmental profiles of related buildings including all used materials in order to found the percentage of environmental impacts of houses foundations to overall environmental impact of building (Figures 1-3).

Table 2: Calculated environmental indicators (PEI, GWP and AP) of houses foundations

Configuration	House 1	House 2	House 3	House 4	Mean
Weight of materials used [kg]	2.28×10^5	1.59×10^5	1.52×10^5	1.41×10^5	1.70×10^5
PEI [MJ]	2.50×10^5	2.21×10^5	2.02×10^5	1.22×10^5	1.99×10^5
GWP [kg CO_2 eq]	0.24×10^5	0.12×10^5	0.18×10^5	0.10×10^5	0.16×10^5
AP [kg SO_2 eq]	70.96	42.44	56.76	35.27	51.36

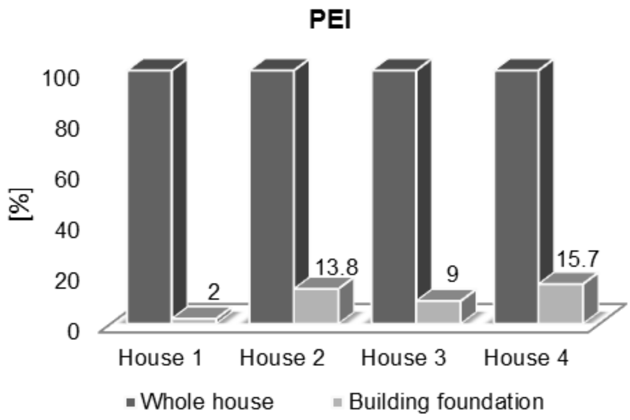

Figure 2: Contribution of houses foundation to PEI of whole building

As it is seen in Figure 1, percentage contribution of materials in building foundation to global warming potential of whole houses ranged from 12.5 to 28 % with average value of 23 % for masonry houses and reached 98 % for wooden house.

Percentage contribution of materials in building foundation to primary energy intensity of whole houses ranged from 2 to 15.7 % with the average value of 10.25 %.

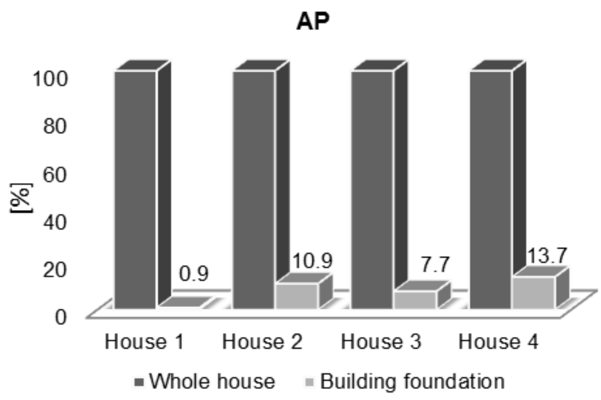

Figure 3: Contribution of houses foundation to AP of whole building

Materials in building foundation of evaluated houses contribute to acidification potential in the range of 0.9 – 13.7 %. Average contribution has been calculated to be of 8.5 %.

In order to allow the environmental indicators to be comparable to the other authors' results, calculated total values have been converted by dividing by floor area, heated volume and total amount of materials in building foundations. Comparison of the normalised values of environmental indicators and is illustrated in Figures 4-6.

The highest normalised values of all evaluated indicators converted to floor areas have been found out for House 3, while the lowest ones for House 2.

Comparing the results of calculated indicators normalised to cubature the House 2 reached the lowest values similarly to the normalization results to floor areas. On the other hand, the most negative values have been calculated for wooden House 1.

Results from the comparison of environmental indicators normalised to total weight of foundations materials were not so clear to interpret and have been very different in dependence on the evaluated indicator.

The average houses foundation environmental impact (Table 3) in terms of GWP have been calculated of 53.175 kg CO_2 eq/m^2 of floor area, 24.87 kg CO_2 eq to 1 m^3 of heated house volume and 0.91 kg CO_2 eq/kg of foundation materials. Average PEI of house foundation reached 632.19 MJ/m^2, 320.83 MJ/m^3 and 1.17 MJ/kg. Much lower values have been calculated for AP of house foundation: 0.17 kg SO_2 eq/m^2, 0.086 kg SO_2 eq/m^3 and 2.95x10^{-4} kg SO_2 eq/kg.

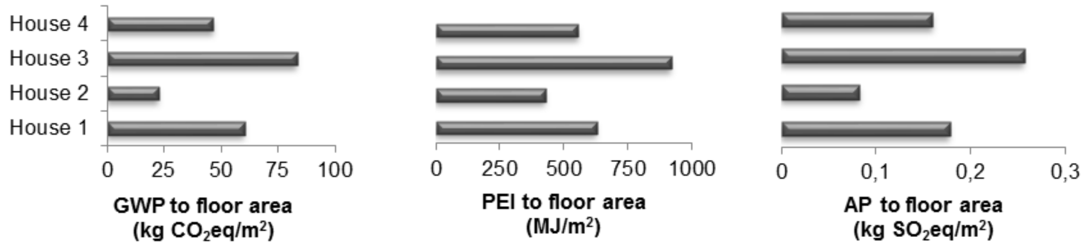

Figure 4: Comparison of calculated environmental indicators (PEI, GWP and AP) of houses foundation converted to floor areas

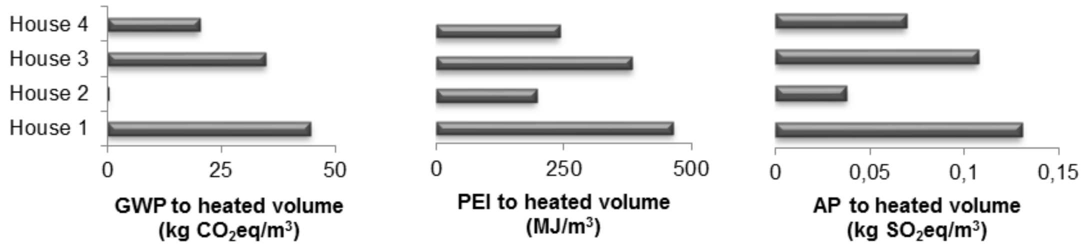

Figure 5: Comparison of calculated environmental indicators (PEI, GWP and AP) of houses foundation converted to heated volumes

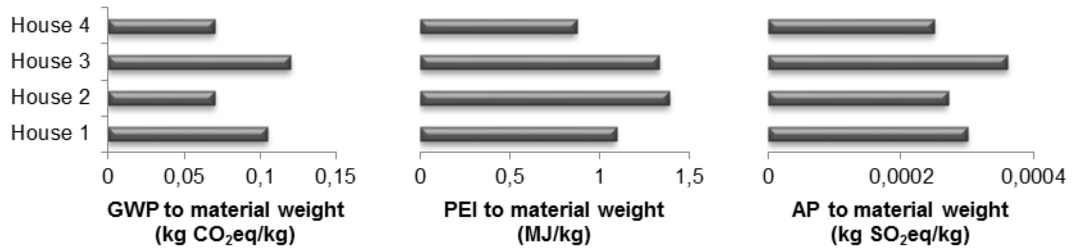

Figure 6: Comparison of calculated environmental indicators (PEI, GWP and AP) of houses foundation converted to total weight of foundations

Table 3: Average values of normalised environmental indicators

	GWP	PEI	AP
Per floor area	53.175 kg CO_2 eq/m^2	632.19 MJ/m^2	0.17 kg SO_2 eq/m^2
Per heated volume	24.87 kg CO_2 eq/m^3	320.83 MJ/m^3	0.086 kg SO_2 eq/m^3
Per weight of materials	0.91 kg CO_2 eq/kg	1.17 MJ/kg	2.95x10^{-4} kg SO_2 eq/kg

4. Conclusions

Environmental performance of materials used for building foundation of four various residential buildings was analysed in the paper. Summarising the results:

- houses foundation materials contribute by 10.25 and 8.5 % in average for PEI and AP, respectively to total environmental impact of building;
- percentage contribution of materials in building foundation to GWP ranged from 12.5 to 28 % with average value of 23 % for masonry houses;
- percentage contribution of materials in building foundation to GWP reached 98 % for wooden house;
- environmental impact of materials used for building foundation calculated per floor area reached values of 53.175 kg CO_2 eq/m^2 (GWP); 632.19 MJ/m^2 (PEI) and 0.17 kg SO_2 eq/m^2 (AP).

Acknowledgment

This research has been carried out within the Grant No. 1/0481/13 of the Slovak Grant Agency for Science.

References

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

Dodooa A., Gustavsson L., Sathre R., 2010. Building energy-efficiency standards in a life cycle primary energy perspective, Energy and Buildings, 43, 1589–1597.

Estokova A., Porhincak M., Ruzbacky R., 2011. Minimization of CO_2 emissions and primal energy by building materials environmental evaluation and optimization, Chemical Engineering Transactions, 25, 1-6.

Estokova A., Porhincak M., 2012. Process of selection of building materials towards sustainable development , Chemical Engineering Transactions, 29, 547-552.

Lia D.Z., Chenb H.X., Huic E.C.M., Zhanga J.B., Lia Q.M., 2013. A methodology for estimating the life-cycle carbon efficiency of a residential building, Building and Environment, 59, 448-455.

Junak J., Stevulova N., 2013, Natural aggregate replacement by recycled materials in concrete production, Visnik Nacionaľnogo universitetu Ľvivska politechnika: teorija i praktika budivnictva, 756, 63-68.

Junak J., Stevulova N., 2011. New direction for waste utilization in civil engineering production Czasopismo Techniczne, 108, 79-87.

Kamar K.M., Ismail E., Ismail E., Abd. Hamid Z., Egbu C., Arif M., Mohd Zin, Mohd. M. Z .N. Ghani.K, Rahim. A.H, 2010. Sustainable and Green Construction, Construction Industry Development Board (CIDB), Malaysia.

Mohammad F.M., 2013. Construction Environment: Adopting IBS Construction Approach Towards Achieving Sustainable Development. Procedia - Social and Behavioral Sciences, 85, 8-15.

Porhincak M., Estokova A., 2013. Environmental analysis of building materials of homes in Slovak Republic – a case study, Int. Journal for Housing Science, 37 (2), 111-120.

Ramesh T., Prakash R., Shukla K.K., 2010. Life cycle energy analysis of buildings: An overview. Energy and Buildings, 42, 1592–1600.

Vilcekova S., Sedlakova A., Kridlova B. E., Culakova M., Geletka V., Kapalo P., 2013. Analysis of Environmental Aspects in High Energy Performance Family House – Case. Chemical Engineering Transactions, 35, 385-390.

Waltjen T., 2008. Passive House - Parts Catalogue. Details for Passive Houses: A Catalogue of Ecologically Rated Constructions (in German), Vienna, Austria, Springer.

Zabihi H., Habib F., Mirsaeedie L., 2012. Sustainability in Building and Construction: Revising Definitions and Concepts. International Journal of Emerging Sciences, 2, 570-578.