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Evaluation of Structures Design Concept of Lower Structure from Embodied Energy and Emissions

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Amount of material and energy sources and the associated environmental pollution is limited over the world. These issues lead to increasing interest in comparing the embodied energy and environmental impacts of buildings using different structure systems and alternative building materials. Buildings play significant role in energy consumption and emission production through all phases of life cycle.
Over the last decade, the development towards sustainability has become important issue in building design decisions. The relative contribution of embodied impacts of building materials and structures has been recognized as being significant, especially for high energy effective buildings. Life cycle assessment (LCA) belongs to broadly used methodology which helps to make decisions in sustainable building design.
The lower structure of buildings has by far the most significant contribution of embodied impacts associated with the construction phase. The goal of this paper is to assess alternative material solutions of lower structure to support decision at the design phase of project. The solutions are towards reduced embodied environmental impacts and improved energy performance. This study uses life cycle analysis in system boundary from Cradle to Gate and focuses on environmental indicators such as embodied energy and emissions of CO_{2eq}. and SO_{2eq}. The selection and combination of materials influence amount of energy consumption and associated production of emissions during building operation. Therefore this study also calculates thermal-physical parameters. Methods of multi-criteria decision analysis (MDCA) are used for the interpretation of results.

1. Introduction

Degradation of environment is currently at huge risk because of factors related to population growth, resource consumption, industrial activity, etc. This situation is causing serious environmental problems which called for new building developments to bridge the gap between this need for reduction of environmental impacts and ever increasing requirements on living (Čuláková, 2012). Building materials as essential components of building constructions and whole buildings play an important role in overall impact on the environment (Eštoková, 2012). Life cycle assessment is the most complex method for quantifying the environmental impacts and performing optimization (Eštoková, 2011). The key factors for selection of building materials are technical and economical parameters, however responsible selection of building materials regarding environmental performance may lead to reduction a negative image of construction sector (Porhinčák, 2013). According to study (Moncaster, 2013) as operational impact from buildings are reduced, the embodied impact are increasing and the last decade has seen increasing regulations for the reduction of energy use and carbon emissions from the operation of buildings.
Selection of materials and technologies for the building construction should satisfy the felt needs of the user as well as the development needs of the society, without causing any adverse impact on environment. In recent years, awareness of environmental aspects has grown in the building and construction sector. Manufacturing processes of building materials contribute for greenhouse gases like CO_2 to the atmosphere. There is a great concern and emphasis in reducing the greenhouse gases

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emission into the atmosphere in order to control adverse environmental impacts (Venkatarama Reddy, 2003). The building construction industry consumes a large amount of resources and energy and, owing to current global population growth trends; this situation is projected to deteriorate in the near future. Buildings consume approximately 40 % of total global energy: during the construction phase in the form of embodied energy and during the operation phase as operating energy. Embodied energy is expended in the processes of building material production (mining and manufacture), on-site delivery, construction and assembly on-site, renovation and final demolition. Recent studies have considered the significance of embodied energy inherent in building materials, with a specific focus on this fraction of sequestered energy (Dixit, 2010). The total life cycle energy of a building includes both embodied energy and operating energy (Ding, 2004): (i) embodied energy - sequestered in building materials during all processes of production, on-site construction, and final demolition and disposal; and (ii) operating energy - expended in maintaining the inside environment through processes such as heating and cooling, lighting and operating appliances.

A great deal of effort has been put into reducing the former as it is assumed that it is higher than the latter. However, studies have revealed the growing significance of embodied emissions in buildings but its importance is often underestimated in lifecycle emissions analysis (Ibn-Mohammed, 2013). Embodied energy is the energy utilized during manufacturing phase of the building. It is the energy content of all materials used in the building and technical installations, and energy incurred at the time of erection/construction and renovation of the building. Energy content of materials refers to the energy used to acquire raw materials (excavation), manufacture and transport to the building site. Embodied energy is divided in two parts: initial embodied energy and recurring embodied energy (Ramesh, 2010).

Historical definitions of zero energy are based mainly on annual energy use for the building's operation (heating, cooling, ventilation, lighting, etc.). The term "net-zero energy" is frequently used to present the annual energy balance of a grid connected building but it does not consider the energy inputs to deliver the building and its components. As such it is not directly associated with the use of the term “net energy” as related to life cycle energy accounting and as defined in ecological economics and in the renewable energy field (Hernandez, 2010). The topic of net zero energy building (nZEB) has received increasing attention in recent years, until becoming part of the energy policy in several countries. In the recast of the EU Directive on Energy Performance of Buildings (EPBD) it is specified that by the end of 2020 all new buildings shall be “nearly zero energy buildings” (Sartori, 2012).

The aim of this study is analysis of environmental indicators such as embodied energy and emissions of $CO_{2eq.}$ and $SO_{2eq.}$ as well thermal-physical parameters for alternative solutions of lower structure.

2. Method of research

Environmental indicators are calculated by the Life Cycle Assessment method. The analysis investigates the role of different building material compositions in terms of the embodied energy from non-renewable resources and the embodied equivalent emissions of CO_2 and SO_2 in nearly zero energy buildings. Embodied energy (EE) is the energy utilized during manufacturing stage of building materials and represents the energy used to acquire raw materials (excavation), manufacture and transport. Similarly, CO_2 emissions (ECO_2 - global warming potential GWP) and SO_2 emissions (ESO_2 - acidification potential AP) represent the equivalent emissions within the LCA boundary – Cradle to Gate. The input data of these indicators are extracted from the LCA database – IBO. In this study, it is also calculated environmental indicator ΔOI3 which describes impact of building material in given structure layer and is calculated according to Eq(1).

$$\Delta OI3 = \frac{1}{3} \cdot \left[\frac{1}{10} \cdot \left(EE_{BM} \right) + \frac{1}{2} \cdot \left(ECO_{2BM} \right) + \frac{100}{0{,}25} \cdot \left(ESO_{2BM} \right) \right] \tag{1}$$

where:

EEBM - embodied energy of one structure layer – building material [MJ/m^2];
ECO_{2BM} - embodied emissions CO_2 of one structure layer – building material [kg CO_{2eq}/m^2];
ESO_{2BM} embodied emissions SO_2 of one structure layer – building material [kg SO_{2eq}/m^2].

Three variant (V0, V1 and V2) was designed to optimally economical and structurally accurate detail of contact of base, external cladding and floor on background terrain. These variant was evaluated it from the standpoint of hygienic criterion, based on the boundary conditions defined in accordance with STN 73 0540:2012 (θ_e = -15 °C, φ_e = 84 %), STN EN 12 831 (θ_i = 18 °C, φ_i = 50 %), and from the theoretical assumption of soil temperature of at a depth of 3 m under the level of adjacent ground (θ_z = 5 °C). To eliminate the thermal loss in structural detail of contact of base, external cladding and floor on background terrain, not only in the floor, but also on outer side of the external structure, we place the thermal insulation (extruded foam polystyrene) from outer side of the base structure with regard to optimal thermo technical sequence of the external cladding and already mentioned base. This will markedly influence the whole course of factor of floor heat transfer on background terrain. At the same time it was necessary to place thermal insulation under the prefabricated light – weight external cladding (in joggle - a band of thermal isolation of thickness of 30 mm).

The critical spaces of junction of the floor structure on the background terrain, base and external cladding in the corners of interior are specific by lowering of surface temperature roughly by 2 °C. In this case, these places are heated from outer side by additional bands of thermal isolation, by which the normative requirements (hygienic criterion) at designing the mentioned building structures and details in the inner working environment are fulfilled.

Characteristics of the assessment design detail bottom reference building construction. The values of physical parameters of building materials applied in the construction details, were based on data contained in the standard STN 73 0540-3 the data given in standard EN ISO 13370.

In the Figure 1 is shown schematic illustration of the considered details of lower structure with material characteristics. In the table 1 is shown materials legend of considered details of lower structures.

In the table 2 is shown the representation of the structural modifications for each considered variants detail (V0, V1 and V2).

Chapter 2 In the Figure 2 – a, is shown schematic illustration of zero variant of lower structure with floor slab with cement spreading the thickness of 200 mm without thermal insulation. In the Figure 2 – b, is shown schematic illustration of first variant of lower structure with floor slab with cement spreading the thickness of 200 mm with XPS insulation base on thickness of 30 mm over the entire height. In the Figure 2 – c, is shown schematic illustration of first variant of lower structure with insulation of floors XPS thickness of 60 mm over the entire surface.

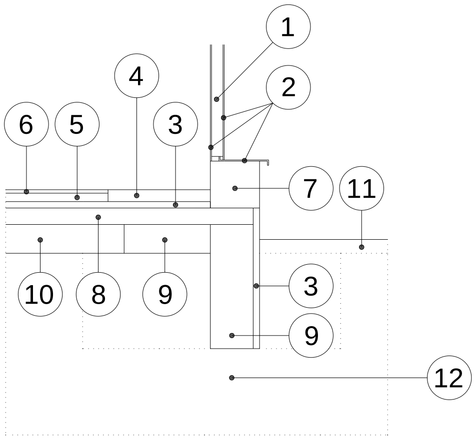


Figure 1: Schematic illustration of the considered details of lower structure - material characteristics

Table 1: Materials legend of considered details of lower structures

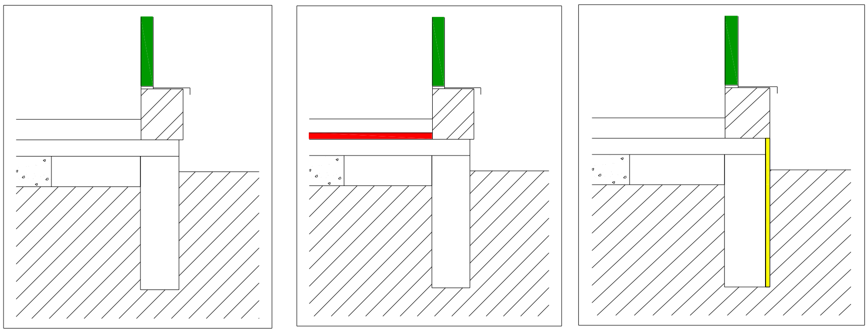
No.	Specification of materials	λ (W/(m.K))	μ (1)
1	Thermal Insulation sandwich panel with polyurethane insulation	0.029	180.0
2	Trapeze - profiled sheet, respectively sheeting	50.00	1,000,000.0
3	Extruded polystyrene XPS (EXP)	0.034	100.0
4	Concrete layer with cement spreading	1.230	17.0
5	Polystyrene concrete (900)	0.235	12.0
6	Concrete screed floor cover	1.050	17.0
7	Masonry of aerated concrete blocks	0.180	7.00
8	Screeding concrete + mesh	1.430	23.0
9	Dense concrete	1.230	17.0
10	Gravel embankment	0.850	4.50
11	The original soil	1.400	1.50
12	Soil (subsoil) - loam	1.400	1.50

Table 2: Thermo-physical parameters of the structural modifications for each considered variants detail

Variant detail	V0	V1	V2
U_{wall} [W/(m^2.K)]	1. 0.418	2. 0.418	3. 0.418
4. U_{floor} [W/(m^2.K)]	5. 1.396	6. 1.396	7. 1.396
8. θ_{si} [C°]	9. 7.59	10. 10.33	11. 10.60
12. f_{Rsi} [-]	13. 0.68	14. 0.77	15. 0.77
16. L_{2D} [W/(m.K)]	17. 1.765	18. 1.449	19. 1.182
20. $L_{2D,wall}$ [W/(m.K)]	21. -0.125	22. -0.125	23. -0.125
24. $L_{2D,floor}$ [W/(m.K)]	25. -0.620	26. -0.620	27. -0.183
28. Ψ_{2D} [W/(m.K)]	29. 1.019	30. 0.704	31. 0.873

3. Results and discussion

The results of environmental indicators in terms of total values per square meter are illustrated in the Figures 3 and 4. The environmental evaluation results and environmental profiles of lower structure variants show that variant V0 achieves the lowest values of EE, ECO_2 and ESO_2. Variant V0 of lower structure can assure the highest reduction of EE by 5 % - 36.68 %, of CO_2 by 22.75 % - 82.16 %, of SO_2 by approximately 2.22 % - 13.36 % in comparison with other alternatives.



a, b, c,

Figure 2: Schematic illustration of variant V0, V1 and V2

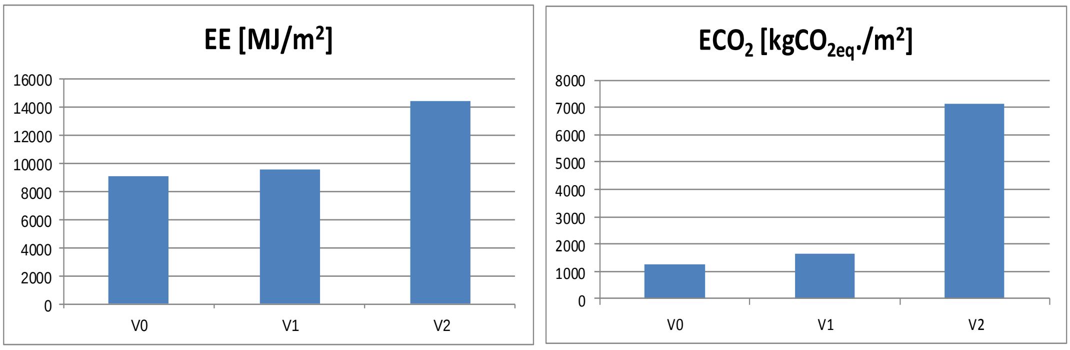


Figure 3: Embodied energy and CO_2 emissions

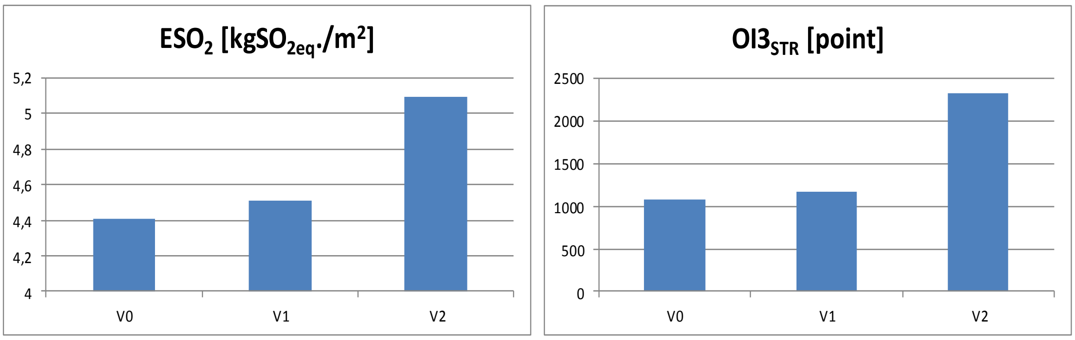


Figure 4: SO_2 emissions and $OI3_{STR}$

Table 3: Results of MCDA for alternatives of lower structures

	1 (V1)	2 (V0)	3 (V2)
CDA	32. 1.9907	33. 2.7103	34. 3.0361
35. IPA	36. 0.2636	37. 0.5	38. 0.5537
39. WSA	40. 0.7364	41. 0.5	42. 0.4463
43. TOPSIS	44. 0.5274	45. 0.4986	46. 0.478

The selected variants of lower structures are evaluated from thermo-physical parameters and environmental indicators in order to obtain total score and to indicate the best option. The results are compared through mathematical methods such as Weighted Sum Approach (WSA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Ideal Points Analysis (IPA) and Concordance discordance analysis (CDA). The best value of total score for methods WSA and TOPSIS is the number nearest to 1.0, for IPA is the number nearest to 0.0 and for CDA is the lowest number. The weighting of assessed indicators is calculated by using Saaty's method in order to elimination of subjectivity (Korviny, 2009).

The variant V2 achieves the worst results of MCDA. The material composition of variant V1 represents the best solution in terms of value of total score of MCDA according to using mathematical methods as seen in Table 3.

4. Conclusion

Based on the results of fine-tuning simulations of experimental building we can be obtain relevant results applicable in practice for the design of passive buildings, in compliance with basic hygienic requirements in terms of structures, indoor environment and also design and use of energy supply systems.

All three evaluated variants of lower structures are designed to meet the same thermal physical parameters. It can be stated that they equally involved in energy consumption of building. The main goal of paper was assessment of designed variants of lower structures from environmental indicators and embodied energy. The variant V0 of lower structure without thermal insulation is evaluated as the best solution. The higher values of embodied energy and CO_2 and SO_2 emissions are caused by extruded polystyrene, concrete and polystyrene concrete in variants V1 and V2.

The future research work will be aimed to evaluation of more variants of lower structures in term of thermal physical properties of used materials and their embodied energy and emissions.

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