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Section: Energy for Buildings

Comparison of Material Compositions of Exterior Wall in term of Environmental and Energy Performance

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Abstract

In world with limited amount of energy sources and with serious environmental pollution, interest in comparing the environmental embodied impacts of buildings using different structure systems and alternative building materials will be increased. The selection of building materials used in the structures (floors, walls, roofs, windows, doors, etc.) belongs to one of the most important roles in the phase of building design. This decision has impact on the performance of the building with respect to the criteria of sustainability. The energy used in the extraction, processing and transportation of materials used in building structures can be significant part of the total energy used over the life cycle of building, particularly nearly-zero energy performance buildings. The environmental impacts are expressed by indicators such as embodied energy (EE) from non-renewable resources, embodied $CO_{2\text{-eq}}$ emissions (GWP, global warming potential) and embodied $SO_{2\text{-eq}}$ emissions (AP, acidification potential) within system boundary from Cradle to Gate. The aim of analysis is identify the environmental quality of material compositions of architectural structure alternatives of exterior wall. The final values of assessments are compared by using methods of multi-criteria decision analysis. The results of the analysis showed that exterior wall designed from ceramic brick and thermal insulation of EPS with graphite can assure the highest reduction of EE by 10% – 37%, of CO_2 by 2% – 14%, of SO_2 by approximately 10% – 57% in comparison with other alternatives.

Keywords: Wall assemblies; energy and environmental indicators; thermo-physical parameters.

Nomenclature

U	heat transfer coefficientvelocity in the direction of (W/(m^2.K))
d	thickness (mm)
c	specific heat capacity (J/(kg.K))
Rh_e/Rh_i	outdoor/indoor relative humidity (%)
Greek symbols	
ρ	density (kg/m^3)
λ	thermal conductivity coefficient (W/(m.K))
μ	diffusion resistance factor
θ_e/θ_i	outdoor/indoor air temperature (°C)

1. Introduction

Nowadays, heating energy demand has become a significant estimator used during the design stage of any new building. The residential housing sector consumes a significant amount of fossil fuel energy and thereby produces a large percentage of greenhouse gas emissions that contribute to global warming and climate change. At present, approximately 40% of the total household energy used is required for space heating/cooling and a substantial amount of that energy is lost through the house walls. Despite the importance of house walls for energy efficiency, most published literature focuses mainly on thermal comfort, environmental impact and economic costs of residential buildings [1]. Little information is available on energy efficient house wall systems that can be used and adapted for various climate conditions with minimal design change and associated cost. The architectural design variables which most influence the energy performance of a building are the envelope materials, shape and window areas. As these start to be defined in the early design stages, designers require simple tools to obtain information about the energy performance of the building for the design variations being considered at this

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phase. The shape factor is one of those tools, but it fails to correlate with energy demand in the presence of important solar gains [1, 2, 3].

As the building area of external envelopes and the heat transfer coefficient (U value) of a building are the most important parameters affecting indoor climate, they have been taken into consideration in detail. The proposed methodology enables to determine the limit values of the building envelope heat transfer coefficients on the basis of ratios of area and volume of building and other design parameters affecting indoor thermal comfort and energy conservation such as orientation, windows type, optical and thermo physical properties of the building envelope [4].

For example in Turkey the insulation of buildings was not a common occurrence until it became obligatory after the publication of the TS 825 Turkish Thermal Insulation Standard. However, most of the buildings still have little or no insulation. The optimum insulation thickness for the different wall types; stone, brick and concrete are usually used in building construction in Turkey. Four cities from different climate zones, determined by the Turkish Thermal Insulation Standard (TS 825); Antalya (1st zone), İstanbul (2nd zone), Elazi (3rd zone) and Kayseri (4th zone) were selected for analysis, and the optimum insulation thicknesses [5].

Currently, there exist no single insulation materials or solution capable of fulfilling all the requirements with respect to the most crucial properties (thermal conductivity, CO_2 emissions, durability etc.). Examples of these may be mineral wool, expanded polystyrene, extruded polystyrene, polyurethane, vacuum insulation panels, gas insulation panels, aerogels, and future possibilities like vacuum insulation materials, nano insulation materials and dynamic insulation materials. That is, for the buildings of today and the near future, several insulation materials and solutions are used and will have to be used depending on the exact circumstances and specifications. As of today, new materials and solutions like e.g. vacuum insulation panels are emerging, but only slowly introduced in the building sector partly due to their short track record. Therefore it will be of major importance to know the limitations and possibilities of all the insulation materials and solutions, i.e. their advantages and disadvantages [6].

2. Methods 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.

The CO_2 emissions (ECO_2 – global warming potential GWP) and SO_2emissions (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 [7].

In this study, it is also calculated environmental indicator ΔOI3. The ΔOI3 indicator for one building material layer indicates by how many OI3 points that layer of building materials raises the $OI3_{KON}$ of a structure. In other words, if we eliminate one layer from a structure the $OI3_{KON}$ of the structure will sink by ΔOI3points. The ΔOI3 indicator is calculated according to Eqn (1) [8].

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

where:

EE_{BM} – 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].

For purpose of reduction of future energy demand, these wall assemblies of alternatives are designed to meet requirements for nearly zero energy houses (U = 0.15 W/(m^2.K)). The thermal-physical parameters are calculated for Slovak climatic conditions [9]:

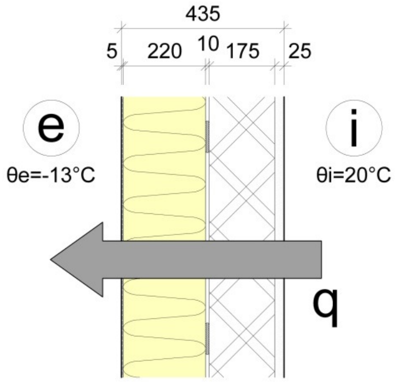
θ_e – outdoor air temperature (–13 °C);

θ_i – indoor air temperature (20 °C);

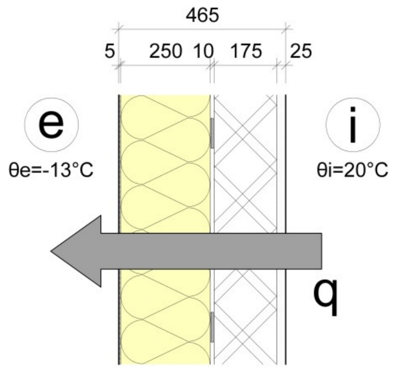
Rh_e – relative air humidity in outdoor (84%);

Rh_i – relative air humidity in indoor (50%).

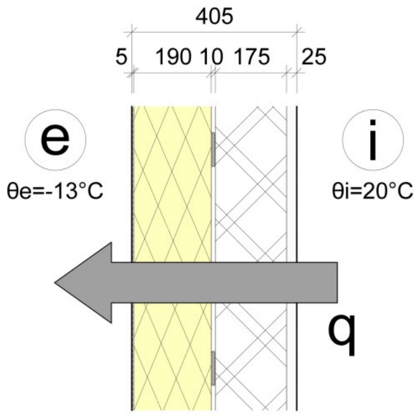
In the Figure 1 alternatives of wall assemblies with various thermal insulationsare shown.



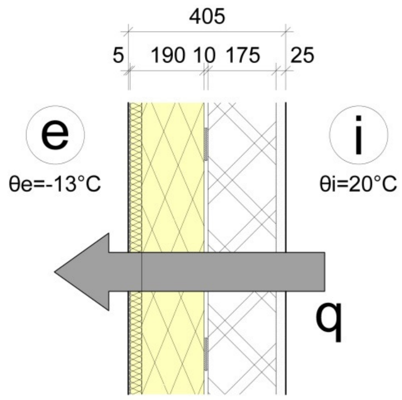
(a) Wall 1



(b) Wall 2



(c) Wall 3



(d) Wall 4

Fig. 1. Wall assemblies with various thermal insulations (a) EPS, (b) mineral wool, (c) EPS with graphite and (d) EPS with graphite and mineral wool

Thermal-physical parameters for evaluated alternatives of wall assemblies are presented in the Table 1.

Table 1. Basic physical parameters of wall assemblies

Number of wall		Wall assemblies	Thickness d[mm]	Density ρ [kg/m^3]	Thermal conductivity coefficient λ [W/(m.K)]	Specific heat capacity c [J/(kg.K)]	Diffusion resistance factor μ [–]
1	1	Silicate plaster	5	1800	0.86	920	19
	2	Thermal insulation – EPS 20	220	20	0.038	1270	40
	3	Adhesive mortar	10	350	0.8	920	18
	4	Ceramic brick	175	800	0.22	960	5
	5	Limecement plaster	25	2000	0.88	790	19
2	1	Silicate plaster	5	1800	0.86	920	19
	2	Thermal insulation– mineral wool	250	130	0.041	1030	1
	3	Adhesive mortar	10	350	0.8	920	18
	4	Ceramic brick	175	800	0.22	960	5
	5	Limecement plaster	25	2000	0.88	790	19
3	1	Silicate plaster	5	1800	0.86	920	19
	2	Thermal insulation- EPS with graphite	190	15	0.038	1450	40
	3	Adhesive mortar	10	350	0.8	920	18
	4	Ceramic brick	175	800	0.22	960	5
	5	Limecement plaster	25	2000	0.88	790	19
4	1	Silicate plaster	5	1800	0.86	920	19
	2	Thermal insulation- mineral wool	30	108	0.036	1020	1
		Thermal insulation- EPS with graphite	190	15	0.038	1450	40
	3	Adhesive mortar	10	350	0.8	920	18
	4	Ceramic brick	175	800	0.22	960	5
	5	Limecement plaster	25	2000	0.88	790	19

3. Results and discussion

The results of environmental indicators in terms of total values per square meter are illustrated in the Figure 2 and 3. The environmental evaluation results and environmental profiles of wall assembliesalternatives show that alternative 3 achieves the lowest values of EE, $ECO_2$and ESO_2.Exterior wall 3 can assure the highest reduction of EE by 10% – 37%, of CO_2 by 2% – 14%, of SO_2 by approximately 10% – 57% in comparison with other alternatives.

The wall assemblies are evaluated in order to obtain total score from assessment results and to indicate the best option. The results are compared through mathematical methods 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 aspects is calculated by using Saaty's method in order to elimination of subjectivity [10].

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is one of the most popular methods in MCDA. TOPSIS was developed by Yoon and Hwang [11]. The basic concept of this method is that the selected alternative should have the shortest distance to the positive ideal solution and the farthest distance from the negative ideal solution [12]. This method assumes that each criterion tends toward a monotonically increasing or decreasing utility [12, 13, 14].

Ideal Point Analysis (IPA) rests upon the deviation between the set of ideal solutions and the set of effective solutions. Although the ideal solution surely almost does not exist, it serves as an important reference model. The best compromise solution is determined as that solution that is the nearest to the ideal one. The increasing distance from the ideal solution for factors located upper on the scale of importance induces greater consequences than the increasing distance from the ideal solution for factors located lower on the scale of importance [15].

Concordance-Discordance Analysis (CDA) is a method widely used in MCA. It consists of comparison of alternatives of pair selection. It measures the degree by which the alternatives of selection and the weights of factors prove or disprove the ratio between the alternatives. The differences in the weights of factors and in the evaluations of criteria are analysed by means of the procedures of concordance and discordance separately [15].

Weighted Sum Approach (WSA) method comes from principle of maximization of benefit, simplification of this method is that it is assumed only linear function of benefit. Process of this method is comfortable to IPA method; resulting sequence of alternatives is opposite [15].

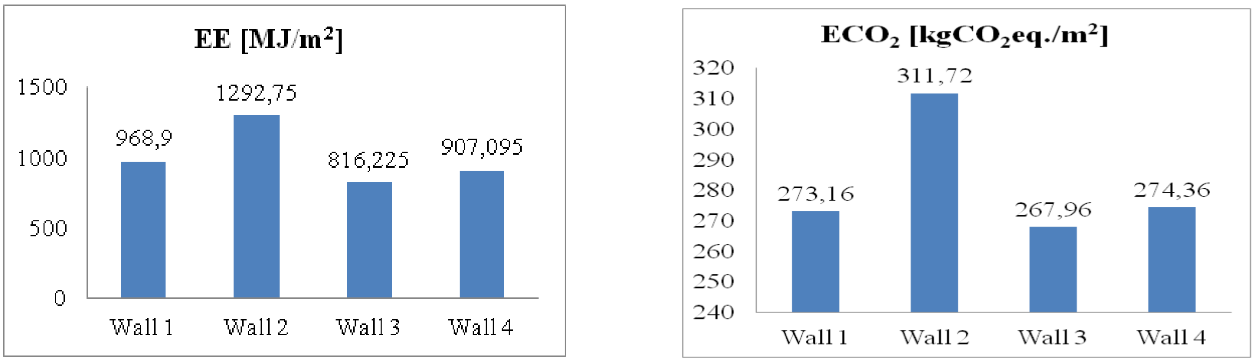


Fig. 2. Embodied energy and CO_2 emissions of evaluated wall assemblies

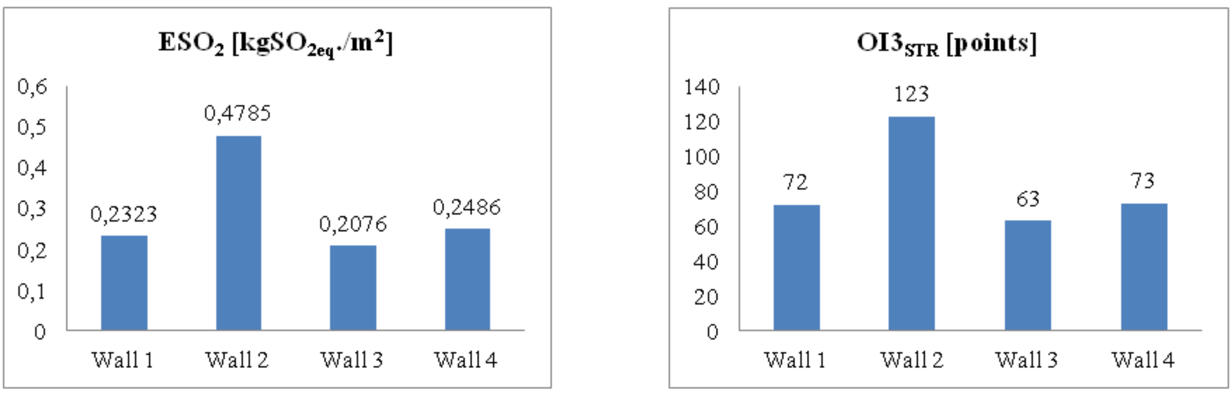


Fig. 3. SO_2 emissions and $OI3_{STR}$of evaluated wall assemblies

The wall assembly 2 achieves the worst results of MCDA. The material composition of alternative 3 represents the best solution in terms of value of total score of MCDA according to using mathematical methods as seen in Table 2.

Table 2. Results of MCDA for alternatives of wall assemblies

	1. (Wall 3)	2. (Wall 4)	3. (Wall 1)	4. (Wall 2)
CDA	0	1,8208	1,8501	5,7351
IPA	0	0,165	0,1939	1
WSA	1	0,835	0,8061	0
TOPSIS	1	0,8305	0,7691	0

In the study [16] was performed the environmental profile of wall assemblies for wooden houses. Environmental aspects were evaluated for sixty alternatives of designed compositions. The determined average values of embodied energy and emissions were 675.86 $MJ.m^{-2}$, –100.30 $kgCO_{2eq}.m^{-2}$ and 0.294 $kgSO_{2eq}.m^{-2}$for EE, ECO_2 and ESO_2, respectively. These values are lower about 17.2% and 137.4% for EE and ECO_2, and higher about 29.4% for ESO_2. The selection of materials based on the plants cause better results of EE and ECO_2. Accordingly, it is advisable the use of environmentally friendly materials (for example wood, straw, fleece etc.) with small environmental impact.

4. Conclusion

The overall environmental and energy performance of building structures is important in achieving more sustainable solution. The careful choice of building materials play significant role in increasing the sustainability of buildings and represent the easiest way for designers to begin incorporating environmental criteria in building project. The wall 3 designed from ceramic brick and thermal insulation of EPS with graphite is evaluated as the best solution. Determined value of wall 3 of embodied energy was 816.225 $MJ.m^{-2}$, CO_2 emissions was 267.96 $kgCO_{2eq}.m^{-2}$ and SO_2 emissions was 0.2076 $kgSO_{2eq}.m^{-2}$ for EE, ECO_2 and ESO_2, respectively. Thermal-physical parameters of EPS insulation with graphite are better in comparison with other evaluated thermal insulations which result in the less of material thickness.The our future research work will be aimed to evaluation of more alternative solutions of wall assemblies in term of various thickness and thermal physical properties of external walls as well thermal insulation materials.

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