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Comparison of building's external wall components based on global warming potential

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Abstract

Lowering environmental impacts in the operational phase of the building's life cycle has been achieved by introducing highly-insulated thermal envelopes in temperate and cold climates. However, the emissions and energy used in other life cycle phases should also be considered. The paper presents the comparison of the building's external wall components based on global warming potential in the production phase. Four types of construction (reinforced concrete, brick, cross-laminated timber and timber-frame) and three types of insulation materials (rock wool, expanded polystyrene and wood fibre) used within external wall components are analysed. Three heat transfer coefficients of the wall components were selected and compared. The results of the study demonstrate the potential of lowering environmental impacts of building external wall components by selecting suitable materials and present the solutions for the optimization of thermal envelopes in the design phase.
Keywords: building's external wall components, global warming potential

Usporedba segmenata vanjskog zida zgrade na osnovu potencijala globalnog zagrijavanja

Sažetak

Korištenje sofisticiranih termalnih izolacija u operativnoj fazi vijeka trajanja zgrade je značajno smanjilo utjecaj na okoliš u područjima blage i hladne klime, no potrebno je uzeti u obzir emisije i potrošnju energije u drugim fazama vijeka zgrade. U ovom će se radu prikazati usporedba segmenata vanjskog zida zgrade na osnovi potencijala globalnog zagrijavanja, ali u fazi proizvodnje građevinskih materijala. Posebno će se analizirati četiri tipa gradnje (armirani beton, cigla, unakrsno lamelirane drvene panele i drveni okvir) i tri tipa izolacijskog materijala (kamena vuna, ekspandirani polistiren i drvna vlakna) koji su korišteni u segmentima vanjskog zida. Odabrana su i uspoređena tri koeficijenta provođenja topline za predmetne segmente zida. Rezultati analize su pokazali potencijal smanjenja utjecaja na okoliš segmenata vanjskog zida uslijed odabira odgovarajućih materijala što predstavlja rješenje optimizacije termalne izolacije u fazi projektiranja.
Ključne riječi: segmenti vanjskog zida zgrade, potencijal globalnog zagrijavanja

1. Introduction

In 2010 buildings were responsible for 32 % of the total global final energy used and 19 % of energy-related greenhouse gas emissions [1]. For buildings constructed in temperate or cold regions, the major part of the life-cycle energy is used during the operational phase of the building [2]. During the past years, tighter regulations on the energy use of buildings have influenced a decrease of operational energy and environmental impacts in operational phase and increased the attention to other life cycle phases, especially the production phase. The low-energy buildings have a higher primary energy use for production than the conventional buildings, therefore it is essential to consider both production and operation phases when minimizing the life-cycle primary use of buildings [3]. One of the main aspects of increasing the energy efficiency of the buildings in temperate or cold regions is improving the buildings thermal envelope by lowering its thermal transmittance, but the environmental impact of highly insulated external wall components should also be analysed in the aspect of the production of building materials. Several studies analysed the environmental impacts of external wall components, for example, Bin Marsono & Balasbaneh [4] compared global warming potential of seven building schemes in Malaysia with different structural materials, however, no thermal insulation was added to external walls due to the hot weather conditions. Monteiro and Freire [5] compared seven alternative scenarios of exterior walls with thermal coefficients between 0.47 and 0.51 W/m^2K for a Portuguese single-family house. Sierra-Perez et al. [6] conducted an environmental assessment study of three types of façade building systems for five climate conditions in Spain and highlighted the impacts of insulation materials. This research similarly to above-mentioned studies [4], [5], [6] considers global warming potential of buildings external wall components in the production phase but considers the design of low-energy buildings with highly insulated thermal envelopes located in Central Europe.

2. Methodology

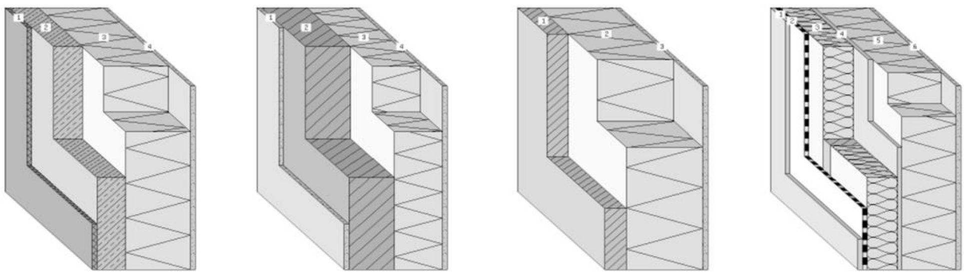
Life Cycle Assessment (LCA) addresses the environmental aspects and potential environmental impacts throughout a product's lifecycle. [7] In the field of building sustainability assessment the LCA is a preferred method for evaluating the environmental performance of the whole building, its materials or components. This study is based on a comparison of external wall components with four structural systems commonly used for the design of low-rise energy-efficient buildings located in Slovenia and other Central-European countries: reinforced concrete (RC), brick (B), cross-laminated timber (CLT), and timber-frame panel (TF) construction. Three types of insulation types used as external thermal insulation composite system are compared: rock wool (RW), expanded polystyrene (EPS) and wood fibre (WF) insulation.

The analysis was carried out with the use of “Baubook construction calculator” [8] providing a free open-source database. The boundaries of LCA are defined as cradle-to-gate, taking into account the production phase with processes of the extraction of raw materials (A1), transport to a manufacturer (A2), and manufacturing (A3), according to EN 15978 [9].

The functional unit of the LCA study is defined as 1 m^2 of external wall component, with selected heat transfer coefficient (U-value) expressed in *W/m^2K*. To evaluate the environmental performance of various external wall components the current paper presents the global warming potential (GWP) for a time horizon of 100 years expressed in *kg carbon dioxide/kg emission*, in accordance with CML 2001 v3.9 [10]. Presented indicator GWP includes both, the contribution to global warming regarding greenhouse gas emissions and the quantities of carbon dioxide stored in the biomass.

2.1. Description of external wall components

In Figure 1 four types of external wall components are presented. All the analysed wall types consist of the construction (concrete, brick, CLT, timber), thermal insulation and finishing (gypsum filler, plaster etc.). Different insulation types (see Table 1) and layer thicknesses were selected to obtain the same heat transfer coefficient in the compared wall envelope components. Compared heat transfer coefficient for walls with averages of *$U_1 = 0.10\ W/m^2K$, $U_2 = 0.165\ W/m^2K$ and $U_3 = 0.25\ W/m^2K$* comply with heat transfer coefficients mostly used for new energy-efficient buildings in the countries with cold winter and warm summer climate conditions.



RC	B	CLT	TF
0.3 cm gypsum filler	1.5 cm lime cement finish plaster (1800 kg/m³)		1.5 cm gypsum plasterboard (900 kg/m³) 0.18 cm polyethylene (PE) vapour brake
16 cm reinforced concrete (1% of reinforcement) (2300 kg/m³)	30 cm vertically perforated brick + thin-bed mortar or glued using PUR (675 kg/m³)	9.5 cm cross-laminated timber, glued, external use (475 kg/m³)	16 cm (13%) 8 cm timber (475 kg/m³) - rough, technically dried (87%) glass wool (18 kg/m³) 1.5 cm gypsum plasterboard (900 kg/m³)
thermal insulation alternatives	thermal insulation alternatives	thermal insulation alternatives	thermal insulation alternatives
0.19 cm silicate plaster (without synthetic resin additive)	0.19 cm silicate plaster (without synthetic resin additive)	0.19 cm silicate plaster (without synthetic resin additive)	0.19 cm silicate plaster (without synthetic resin additive)

Figure 1. Building's external wall components

Table 1. Properties of thermal insulation alternatives

Thermal insulation alternatives	Density [kg/m³]	Thermal conductivity [W/mK]	GWP per mass [$kgCO_2$equ./kg]
Rock wool (**RW**)	120	0.039	1.93
Expanded polystyrene (**EPS**)	15.8	0.040	4.17
Wood fibre (**WF**)	130	0.046	-0.804

3. Results and discussion

In Figure 2 the global warming potential of external wall components are presented.

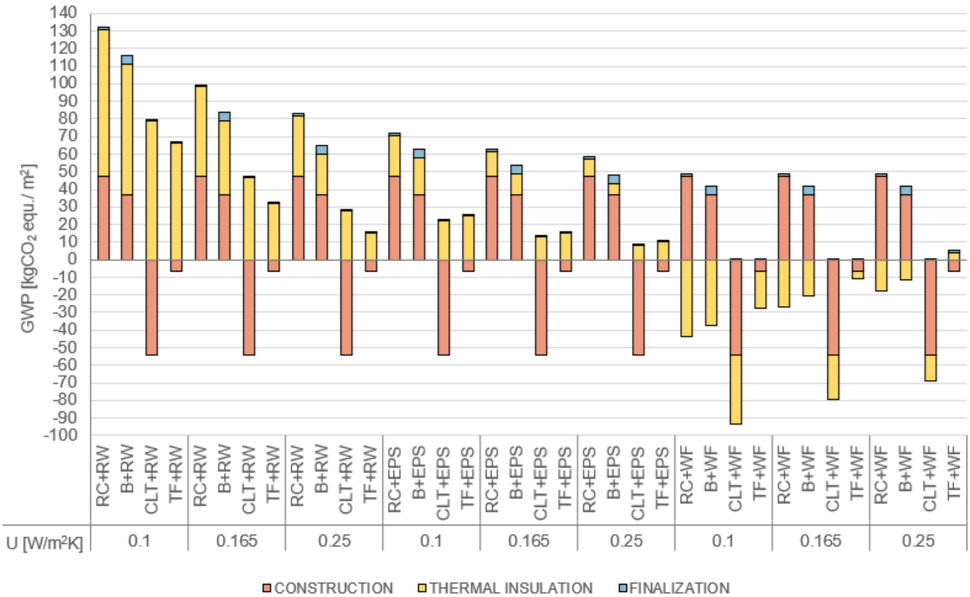


Figure 2. Global warming potential of external wall components

Concerning the production phase of external wall components, both construction and thermal insulation material have high impacts on overall global warming potential of external wall components. Timber structures, especially the cross-laminated timber (CLT) show negative global warming potential, due to the quantities of carbon dioxide sequestered in the biomass. However, it is necessary to point out that the negative impacts on GWP because of carbon sequestration considering other life-cycle phases are only achievable in the case of proper disposal and waste processing of building materials. The reinforced concrete presents with the highest global warming potential in comparison with structural materials. Analysis of thermal insulation materials used for non-ventilated façade system shows the rock wool insulation has the highest global warming potential. External wall components with RW insulation and $U = 0.1\ W/m^2K$ have at least 45 % higher GWP potential than

components with EPS insulation. However, when comparing the GWP of thermal insulations concerning the mass (see Table 1), the RW insulation shows better environmental performance than EPS insulation. For non-ventilated façades without any substructure in the thermal insulation element, only the RW insulation with high density (120 kg/m³) is applicable, thus representing worse environmental performance than EPS when comparing 1m² of wall components. Selection of wood fibre insulation represents a good alternative to RW or EPS insulation considering global warming potential on account of sequestered carbon in the wood fibres. WF insulation as a substitute to RW insulation can contribute to at least 85 % lower GWP of the wall component and in the case of substitution with EPS, the reduction of GWP is at least 40 %.
When comparing whole wall components, it is seen from Figure 2 that TF construction with RW insulation and $U=0.10\ W/m^2K$ has a similar GWP as brick construction with EPS insulation. In the optimization of external wall envelope, all the materials within a wall component should be chosen carefully, especially when comparing wall components with low thermal transmittances.

4. Conclusion

The global warming potential analysis of external wall components shows that both construction and insulation materials overtake a large impact share on GWP. Comparison of construction materials shows that the timber construction systems present with lowest GWP, due to the carbon sequestered in the biomass. The CLT construction had the lowest environmental impact due to the largest quantities of biomass in the wall components. The RW insulation showed the highest footprint in the production phase, considering the thermal insulation materials, therefore EPS and WF insulations present as better alternatives for non-ventilated facades without additional substructures.
The results of the study show possibilities for optimization of building envelopes by identifying the critical materials. The comparison of global warming potential of building's external wall components can serve as a guideline for designers and developers in the design of low-energy buildings in temperate and cold climates.

The extended paper of this research with additional environmental indicators and in-depth analysis of building envelope components has already been published in the international scientific journal [11].

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