Eco-Sandwich Wall Panel System, the Sustainable Prefabricated Wall Panel System Made of Recycled Aggregates

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Abstract
This paper presents the life cycle analysis of the ECO-SANDWICH wall system, an innovative ventilated prefabricated concrete wall panel with integrated mineral wool insulation allowing very low energy design and retrofit of buildings. The purpose of this research and development of the ECO-SANDWICH is to encourage the reuse and recycling of construction and demolition waste as well as to reduce utilization of natural resources. The substitution of conventional thermal insulation materials by Ecose® based mineral wool produced using innovative and sustainable technology leads to additional environmental benefits through the reduction of embodied energy, embodied carbon and production of by-product wastes.

Keywords:
building envelope, prefabricated concrete wall panel, recycled aggregates, life cycle analysis, Ecose® based mineral wool

1 INTRODUCTION

Construction and demolition waste (CDW) has been identified by the European Commission as a priority stream because of the large amounts that are annually generated and the high potential for reuse and recycling embodied in these materials. Arising CDW along with the available average recycling rates of CDW for Croatia and some of its neighboring countries is shown in Table 1. Indeed, a proper CDW management would lead to efficient and effective use of natural resources and would as well help mitigate the environmental impacts to the planet. For this reason, the Waste Framework Directive [1] requires Member States to take any necessary measures to achieve a minimum target of 70% (by weight) of CDW by 2020 for preparation for reuse, recycling and other material recovery, including backfilling operations using nonhazardous CDW to substitute other materials. On the other hand, energy performance of buildings is an equally important issue in the EU and worldwide. The present condition of the existing building stock in Croatia and its neighboring countries is deeply unsatisfactory. Most buildings are 'substandard' in terms of energy efficiency, comfort and health. The largest share of energy consumption in buildings in Croatia is used for space heating (56% and 52% in residential and nonresidential buildings, respectively) and more than 83 % of buildings consume from 150 to 200 kWh/m^2/a of energy for heating. In EU 27 buildings consume around 40 % of energy needs and account for 36 % of EU's CO_2 emissions.

The ECO-SANDWICH wall system, conceived and developed at the Faculty of Civil Engineering in Zagreb, seeks to tackle all of the issues outlined in the preceding paragraph. The ECO-SANDWICH wall system is an innovative prefabricated ventilated wall panel with integrated core insulation allowing very low energy design and retrofit of buildings. It consists of two precast concrete layers interconnected through stainless steel lattice girders. Around 50% of the total aggregate quantity needed for production of concrete layers has been replaced with recycled aggregate obtained from CDW. A newly developed mineral wool manufactured using Ecose® Technology, which uses biobased minerals free from formaldehyde, phenol and petrochemicals, is used as a thermal insulation material. Being harmonized with both Energy Performance of Building Directive - EPBD (2002-91 EC), its Recast EPBD II (2010-31-EU) [2] and EU Waste Framework Directive (2008/98/EC), the ECO-SANDWICH wall system is expected to facilitate the implementation of both legislations by providing a market for recycled CDW and by substantially improving the energy balance of the existing as well as planned building stock.

Country	Arising CDW [million tons]	CDW reused or recycled [%]
Bulgaria	7.80	N/A
Hungary	10.12	16
Romania	21.71	N/A
Slovenia	2.00	53
Croatia	2.34	7
Serbia	1.00	0

Table 1: Average recycling rate of CDW.

The potential of the ECO-SANDWICH in the aforementioned sense has been recognized by the European Commission as funding for market penetration and further development of the wall system has been approved through the EU's CIP-EIP Eco-Innovation 2011 initiative. This paper will present an LCA model that has been developed with the aim of preliminary assessment of embodied energy, embodied carbon and production of by-product wastes during the life cycle of the ECO-SANDWICH panel. A comparison with a generic concrete EPS-core wall panel is also given.

2 LCA OF THE ECO-SANDWICH

2.1 Goal and scope definition

The developed LCA model aims to assess embodied energy, embodied carbon and production of by-product wastes during the life cycles of the ECO-SANDWICH panel and a generic EPS-core wall panel. In order to achieve this goal, the panels were analyzed during different stages of their life cycle, namely resource acquisition, panel manufacture, transport to the construction site and installation, maintenance and use, and, finally, demolition of the panels, recycling of components and disposal of residual wastes.

2.2 Functional unit

In order to achieve an objective comparison between the panels, a functional unit of one panel with dimensions of 6.2x2.8m was selected in a way to achieve system equivalency. Both panels enable construction of buildings with the same internal useable floor area and internal useable building volume. The assumed life span of the panels was 50 years with no maintenance necessary in that period. It was assumed that the panels will be used for construction/retrofitting of buildings located in Zagreb, Croatia with an in-building generation of heat with natural gas furnace. The system equivalency does not hold true in terms of thermal properties of the panels and the use of recycled concrete. Concrete for the ECO-SANDWICH is produced using 50% of aggregates obtained from CDW whereas it is assumed that the generic concrete EPS-core panel is manufactured using virgin aggregate only.

2.3 Life cycle inventory analysis

The scheme of the model used for assessment of environmental impacts of the ECO-SANDWICH wall panel during its life cycle is depicted in Figure 1; SimaPro software [3] was used to model the entire life cycle.

The ECO-SANDWICH consists of two precast concrete layers; recycled concrete aggregate and recycled brick aggregate is used in production of concrete for the inner and outer layer respectively (around 50% of total aggregates needed in production of concrete is obtained from recycled CDW, and the exact quantities were entered in the model). The exact quantities of cement and water used in production of concrete for the panel were also incorporated in the model. The weight of steel used for reinforcement and coupling of concrete layers amounts to around 100 kg and the total weight of Ecose® mineral wool used in one panel is around 90kg. The total weight of one ECO-SANDWICH wall panel is around 5900 kg.

The generic wall panel that was modeled consists of two precast concrete layers (with a thickness of 6 cm each) and 10cm EPS core (volume weight 30kg/m^3) as insulation. Same quantities of concrete components were used in the mix as for the ECO-SANDWICH panel, save for the fact that only virgin aggregate was used. Also, same types and amounts of steel for reinforcement and coupling of layers were assumed. The total weight of one generic wall panel amounts to around 5260 kg.

The data on energy and materials used in modeling of panel components and manufacture of panels were obtained from the partners in the ECO-SANDWICH project. However, if it was found during the compiling of LCI data that the necessary data was not sufficiently reliable or lacking, process information from SimaPro databases [4, 5] were used due to limitations of time and cost. Transportation was taken into account using appropriate maps to determine the distances between the facilities involved in the processes of resource acquisition, panel manufacture and panel recycling/disposal as well as the distance from the panel production factory to the construction site; equal assumptions were made for both panels, i.e. both panels produced at the same factory with material obtained from the same suppliers and only road transport is used. Functional unit for transport was assumed to be ton-kilometers (tkm) which is equal to transport of one ton of goods over one kilometer.

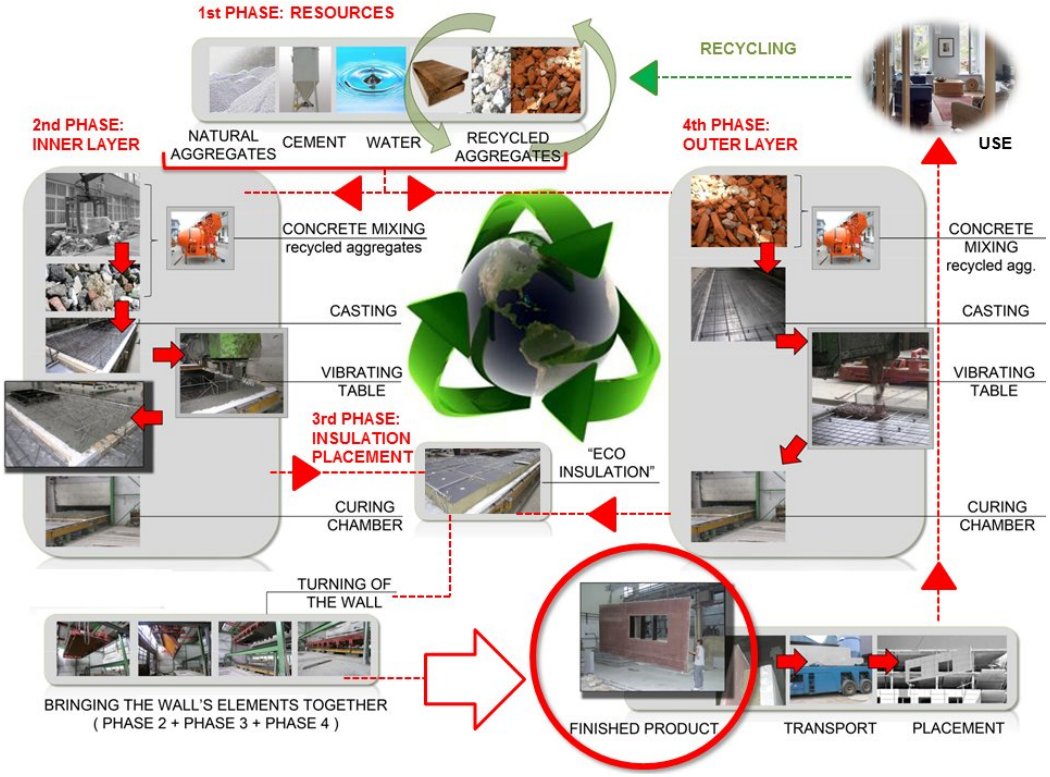

Figure 1: Life cycle model of the ECO-SANDWICH panel.

2.4 Assessment methods and impact categories

As outlined in the goals and scope definition, our aim was to assess the life cycles of the ECO-SANDWICH panel and a generic EPS-core concrete wall panel. Single issue methods were used to achieve this goal. Embodied energy was calculated using the method to calculate Cumulative Energy Demand (CED) as published by ecoinvent version 1.01 and expanded by PRé Consultants for energy resources available in SimaPro database [3]. Characterization factors for nonrenewable fossil resources impact category were used. Embodied carbon was calculated using the IPCC 2007 GWP 100a method employing climate change factors of IPCC with a time frame of 100 years.

3 RESULTS OF THE LIFE CYCLE ASSESSMENT

The results of the performed life cycle analysis for the ECO-SANDWICH and a generic EPS-core concrete wall panel can be seen in Figure 2. It can be seen that the maintenance and use phase has the largest contribution to the embodied energy and embodied carbon impact categories for both panels. The more favorable effect in the use phase of the ECO-SANDWICH stems from the possibility of achieving superb thermal performance through combination of recycled concrete, Ecose® mineral wool and a ventilated layer. As a side note, a way of achieving even better thermal performance of the ECO-SANDWICH was also conceived and will be implemented through the CIP Eco-innovation 2011 initiative.

Resource acquisition also presents s significant contribution to the overall impact of the ECO-SANDWICH as well as the generic panel. Although the ECO-SANDWICH uses significant amount of recycled aggregates, the use of Ecose® mineral wool as opposed to EPS insulation weighs more favorably for the ECO-SANDWICH (see Table 2). Observing the total impact of both panels, it can be seen that the use of the ECO-SANDWICH allows for saves of around 46% and 39% per panel in terms of embodied energy (MJ) and embodied carbon (kg CO_{2eq}), respectively.

A possibility that the use of the ECO-SANDWICH presents in terms of fostering more efficient and effective management of construction and demolition waste is also worth mentioning. As part of the ECO-SANDWICH action proposal preparation, a significant effort was made to obtain data on the types and amounts of CDW that are generated in Croatia and neighboring countries. According to the Croatian Environmental Protection Agency, 46152.05 tons of concrete CDW and 15823.56 tons of brick CDW were generated in 2009. Therefore, by applying the ECO-SANDWICH (i.e. by implementing the strategy that is described in detail in the ECO-SANDWICH action proposal [6]) around 16% of concrete CDW and 23% of brick CDW would be recycled in Croatia. Additionally, around 12272 tons of recycled brick aggregates and 6136 tons of recycled concrete aggregates would be reused in the ECO-SANDWICH wall panel systems on the planned replication market.

4 CONCLUSIONS

Large amounts of recyclable and reusable construction and demolition waste that are annually generated coupled with an exigent need to improve energy performance of the building stock in the EU and neighboring countries present an excellent opportunity for development of green solutions. The ECO-SANDWICH panel, a ventilated prefabricated wall panel that utilizes recycled CDW and mineral wool produced using innovative and sustainable Ecose® technology, tackles these priority issues in an eco-innovative format through the following: by encouraging reuse and recycling of CDW in order to shift CDW management from disposal to recycling; by reducing utilization of natural resources thus preventing landscape degradation; by promoting the substitution of conventional thermal insulation materials with mineral wool produced using innovative and sustainable technology, therefore leading to a reduced environmental impact; and, by promoting implementation of prefabricated, energy efficient products in order to enable reduction of primary energy consumption in residential and commercial buildings.

Figure 2: LCA results (values per panel).

	ECO-SANDWICH		EPS PANEL	
	MJ	kg CO_{2eq}	MJ	kg CO_{2eq}
concrete	7,130	1,354	4,720	890
insulation	1,380	131	5,106	220
steel	1,980	107	1,980	107
TOTAL	10,490	1,592	11,806	1,217

Table 2: Environmental impact of panel components.

The performed LCA analysis presented in this paper indicates the potential of the ECO-SANDWICH wall system in terms of reducing embodied energy and embodied carbon. By comparing the ECO-SANDWICH with a generic EPS-core concrete wall panel, it can be seen that the use of ECO-SANDWICH allows for significant saves - around 46% of embodied energy and around 39% of embodied carbon per panel for a life span of 50 years. However, in order to better highlight the environmental benefits of the ECO-SANDWICH wall system and indicate the possibility for further optimization, a detailed LCA study using a comprehensive impact assessment method such as the Eco-indicator 99 is necessary and will be performed as part of the EU's CIP Eco-Innovation 2011 initiative.

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