The embodied carbon analysis of a nearly Zero Energy Building (nZEB) MgOSIPs house in the UK

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ABSTRACT: The construction industry is changing rapidly where sustainability has become the key word, driving all innovations. Every new material is graded for its environmental impact and the most commonly used technique for this is the Life Cycle Assessment (LCA). This paper attempts to look at the LCA of a specific Magnesium Oxide Structural Insulated Panel (MgO SIP) used for a home in North England – the focus is on embodied CO2 and not operational CO2. The LCA compares the environmental impact across six indicators - Global warming, Acidification, Eutrophication, Formation of ozone, Depletion of Ozone and Primary energy. This is right across the life cycle phases of raw material extraction, manufacturing, on-site construction, transportation, use and end of life/disposal. The result showed that this specific MgO SIP does not score higher than the conventional SIPs as it is manufactured in China and assembled in UK thus nullifying the sustainable impact. In fact, these MgO panels present negative environmental impact. However these MgO SIPs can score over the conventional SIPs and emerge environmentally friendlier if these MgO SIPs are manufactured domestically. Although this is a context-driven conclusion, the paper does highlight the potential of this MgO SIP for attaining the nearly Zero Energy Building (nZEB) objective set by UK.
KEYWORDS: Zero Energy Building (nZEB), Magnesium Oxide (MgO), Structural insulated panels (SIPs), Life Cycle Assessment (LCA), embodied CO2]

1. INTRODUCTION

Globally, buildings and construction account for 36% of global final energy use and 39% of energy-related carbon dioxide (CO2) emissions, [1][11]. Under the climate change act 2008 UK has been committed to reduce the greenhouse gas emission by 80% in 2050 [2][15], currently UK has around 27 million homes and the number is on the rise. The building sector is the largest energy consumer in comparison to all other sectors with CO^2 emissions rising to 9.6Gt in 2018 from 7.7Gt in 2000[10. There are two main factors that play major role in greenhouse gas emission reduction, first is the envelope, the thermal efficiency of the building and second the operation carbon [15]. The European 2050 roadmap aims to reduce energy use, As a result, the European Performance of Buildings Directive (EPBD) policy requires all new building to be nearly Zero Energy Building (nZEB) by 2021, now the nZEB requires commercial and residential to be high energy efficient performance and to be supplied with renewable technologies on site or nearby [11][13]. To achieve nZEB a building should not exceed energy consumption per unit area per year (kWh/m2/year). Ofcourse the targets differ by country, for example Austria have set their target as 160 kWh/m2/year, France 40-65 kWh/m2/year and the UK 44 kWh/m2/year [13]. First, the most feasible approach is the selection of the right building materials, where all the walls, windows and door have high thermal resistance and airtight. Secondly, reduce the primary energy use in the building through advance mechanical systems, and thirdly on-site renewables should be used as the primary source of energy or nearby stations. In the UK, the Committee on Climate Change (CCC) [13] has recently reported that energy-inefficient and high-carbon housing is jeopardizing the UK's chances of meeting its energy reduction targets [14][17][18]. These types of buildings necessitate the need for very high energy performance and will commonly require renewable technologies, however the embodied carbon impact is usually not considered. Over the years prefabricated construction has been promoted as a strategy to reduce building carbon emission, prefabrication is the process of manufacturing building materials and delivering to the site to reduce construction waste and time [14].

In this study, a new type of a prefabricated SIPs system the (MgOSIP) that is capable of possibly meeting nZEB standards has been tested on a real-world case study in the North West of England. The SIPs system offers several improvements over conventional construction and, in this paper, the embodied CO^2 impact is considered using life cycle assessment (LCA) techniques. This paper reports, for the first time, the LCA of a specific Magnesium Oxide (MgO) SIPs system, sold under the brand name of Dragonboard. The panels are assembled in the UK, with the (MgOSIP) boards themselves manufactured in China and shipped to the UK. Using LCA techniques, this specific SIPs homes embodied CO^2e is 18 kg CO2e/m2/year.
Similar results were found in the study by Peixian Li et al [6] in 2018, who quoted a much lower figure of 13.3 kg CO2e/m2/year. To the best knowledge of the author, this paper provides the first LCA of this specific type of MgO SIPs panel for a home in the UK.

1.1 Preference for MgO SIPs

Magnesium Oxide Structural Insulated Panels (MgO SIPs) are gaining preference as it has the potential to outperform the conventional materials of construction like cement, gypsum, plywood, plastics and Oriented Strand Board (OSB) as it is resistant to flame, water, mold and even insects [6]. These SIPs are emerging as one of the good methods for envelope system of sustainable housing. In this case study of the house in Heswall North England, the external walls, the floor and the roof used the DragonBoard MgO SIPs.

Figure 1: Section of the external wall/ground floor/roof

MgO SIP panels are the most advanced contemporary method of construction in the field of prefabrication construction, to reduce the impact of Co^2 emissions and the closest approach to achieve nZEB agenda. The prefabricated SIPs, DragonBoards, are made of Magnesium oxide composition that has a cement texture which acts as a durable insulation material. These sandwich MgO panels are energy efficient and composed of 3 main layers: MgO materials on both side and EPS foam in the middle.

The measurement of the prototype External MgOSIP panel:

1. MgO boards of 24mm
2. MgO boards of 24mm
3. Fibre cement 100mm
4. Silicon 80mm
5. Plaster 150mm

Table 1. MgOSIP external wall measurements.(The U-Value of the external wall was measured at 0.16 (Passive Houses U-Value ranges from 0.10 to 0.15 W/(m²K)).

All the required MgO SIPs were bought from the local supplier of DragonBoard in UK, who in turn said that the MgO itself comes from China. Thus the embodied CO^2e takes a huge jump the moment this import cost is added, subduing the overall score.

2. METHODOLOGY

To study the embodied Co^2e of the MgO SIPs system, a single-family house was selected in Heswall North England of a total built area of 92m2. The house consists of one Master-bedroom (6m x 4m), bathroom (2.6m x 3.3m), living room (7m x 6.7m), office (3m x3m) and utility room (2m x 3m). This LCA software and related datasets are compliant with ISO 14040/14044 or EN 15804 [7]. This LCA software covers life cycle stages from cradle-to-grave with separate reporting to the extraction of raw material, manufacturing, transportation, onsite construction, operation and disposal/reuse, but our study area will focus on the embodied carbon. There are multiple LCA tools available in the market such as OneClickLCA, Gabi6, SIMAPro, and Athena.

2.1 System boundary.

For this study, OneClickLCA has been selected because the University of Liverpool has obtained the license of the software [7].
More importantly, most of the software lack the wall assembly in their database, since the MgO boards are fairly new in the market and they have limited information about them. However, OneClickLCA, at our request, allowed modification of the MgOSIP wall assembly in the program, making calculation much easier.

the program breaks down the calculation into five main criteria:

1. Foundations and substructure
2. Vertical structures and façade

3. Horizontal structures: beams, floors and roofs (Sven Schimschar, Michelle Bosquet, Nesen Surmeli, Andreas, 2013)
4. Other structures and materials
5. Building technology

Table 2. OneclickLCA's calculation criteria.

Each criterion is further broken down into sub-criteria and requires a specific input of EPD (Environmental product documents) obtained from the database, quantity, measurement and transportation distance. The program uses Tool for the reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), which was developed by the U.S. Environmental Protection Agency [7]. The system will calculate the 6 main environmental impact categories - Global warming, Acidification, Eutrophication, Formation of ozone, Depletion of ozone, and Primary energy [8].

3. DATA COLLECTION

In order to measure the total embodied carbon of a residential detached home a two-storey building, (see Figure 1), the house was built in 2016 in Heswal a city

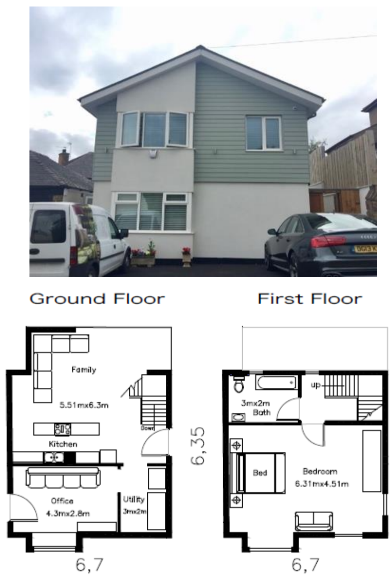

Figure 2. Front elevation and floor plans of the MgOSIP house in UK.

of Wirral , North West England, UK from DIPs panels(MgOSIP) and has been selected as the case study for this paper. Dragonboard Ltd is an SME based in the North West of England [9] and is the supplier of DIPs panels across Scandinavia, France, Ireland, UK, the Middle East and Far East. The SIP house is constructed with DIPS (MgOSIP), concrete, steel, glass, aluminum, insulation, glulam and uPVC. The ground floor consists of an office, utility room and open plan kitchen and family room. The first floor consists of a bathroom and one large bedroom and the total Gross Floor Area (GFA) is 92 m^2.

Parameters	SIP House
No of floor	1 Floor
Total area	92m2
External	Dragon Board Sip Fiber cement 0.10M Silicon 0.08m SIP Expanded Polyvinylchloride 0.0120m SIP ESP Expanded polystyrene 0.1270 SIP Expanded Polyvinylchloride 0.0120m Plasterboard 0.01250
Ground floor	Dragon Board Sip Aerated concrete slap0 .40m Sand and gravel 0.20m SIP ESP Expanded polystyrene 0.150m Underlay rubber 0.010m
Roof	Dragon Board Roof tile 0.020m Roofing felt 0.020m SIP Expanded Polyvinylchloride 0.0120m SIP ESP Expanded polystyrene 0.150m SIP Expanded Polyvinylchloride 0.0120m
Window glazing	Triple Glazed
Infiltration rate	0.8 ac/h estimated
HVAC system	Thermal store used for heating and DHW MVHR Air source heat pump
Occupancy rate (m2/person)	46

Table 3. Characteristics of the SIP house in Wirral UK

3.1 Power

The house is powered by 100% grid connected electricity with no gas supply. The electricity powers all M&E systems inclusive of plug loads, appliances, lighting, thermal storage heating, an immersion heater, an Air Source Heat Pump (ASHP) and a Mechanical Ventilation with Heat Recovery (MVHR) system, external CCTV cameras and WiFi. No renewable solar, thermal energy technologies or battery storage systems are currently in place.

4. RESULT

It was found that the total embodied Co^2e of the MgOSIP house is 18 kg CO2e/m2/year, when compared to nZEP target for the UK the MgOSIP house has relatively small amount of carbon emission CO2e/m2/year. However, the number could have been nearly zero if the transportation for MgO was sourced locally. The mode of transportation plays a major role in calculating the embodied carbon because its related to the consumption of fossil fuel, specially when the MgO SIPs panels are transported from China's warehouse to England where the assembly for the MgOSIP takes a place. Based on the calculation of the embodied carbon it is assumed that the MgO transportation has the highest impact to Global warming potential (GWP) by 20.2%, acidification 10.3%, Eutrophication 9.2%, primary energy 16.6%.

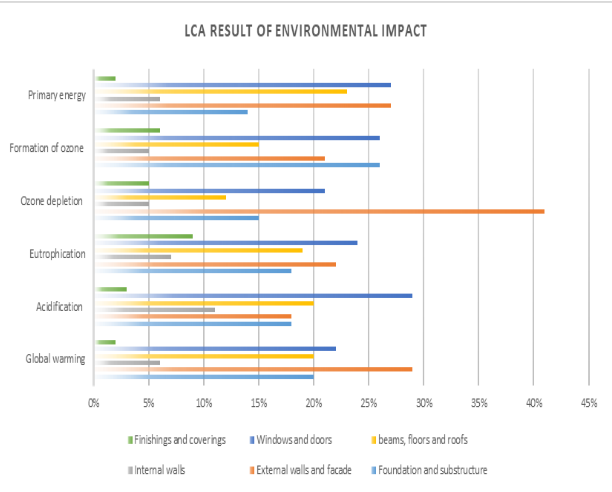

Table 4 : LCA result of the environmental impact of the envelop system.

Even though the panels partially were manufactured in the UK but the MgO panels imported from china the system will add the transportation in the total Co^{2}e calculation, which will spike the environmental indicators resulting a negative impact on the overall environment. Nonetheless, this could be prevented if a substitute to MgO was sourced locally.

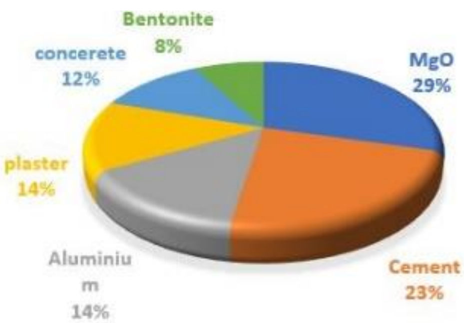

Figure 3: Figure 1: Most contributing materials (Global Warming) in MgOSIP house.

As a result, MgO panels present negative environmental impact mainly due to long distance transportation from factory to manufacturing site and if we compare them to the other method of construction Dragonboards are in fact not sustainable at this stage. Similar results were also found in [6][7]. In addition, the use of Oneclicklca was beneficial because it provides details analysis of each materials in accordance with environmental indicators and provides suggestion for a substitute materials.

5.CONCLUSION.

The study of the prototype clearly shows that MgO panels do present a negative environmental impact and this is mainly assumed to be the long-distance transportation from factory to manufacturing site. And this study shows conclusively that when compare the MgO SIP system to the other methods of construction, DragonBoards technology used in the SIP house do not show optimum solution until now. However, DragonBoards SIPs panel have a great potential in meeting net zero building by 2050 if the prefabricated MgO panels were manufactured locally using local materials. If the substitute to MgO was sourced locally the embodied Co^{2}e of the SIPs can be subsided significantly resulting very low or nearly zero embodied carbon emission, also MgOSIP construction has the ability to save energy due to insulation quality when paired with renewable energy off the grid like the photovoltaics solar panels and/or battery storage.

As a result, SIP systems could be the potential government investment to the road nZEP 2050.

Therefore, further research is required to optimize the Dragonboard potential. This research aims to develop alternatives strategies to modify the environmental impact of the MgO SIP panels to minimize the effect of embodied carbon to meet the passiveHaus standards and (nZEB) 2050 plan.

6.LIMITATION

As the prototype used MgOSIP system, there is currently no knowledge whether MgO can be substituted with some other metal or biodegradable chemical compound. The MgO is mined and transported from China and it is not known whether it would be viable to get the same from other Magnesium ore mining countries. It is also not known why MgO is preferred and not any other material. There are limited research and data around the use of MgO as an durable material in the prefabrication industry and why the country is unable to manufacture a similar or even original substitute locally since the panel sandwich is assembled domestically, sourcing an alternative material to MgO will subside the greenhouse gas emission significantly. Thus, more research is required to find out an alternate for MgO, which could be sourced within UK or nearby, thereby bringing down the embodied Co^2e drastically. And if we can reduce the embodied carbon to nearly zero and source our energy the operational carbon from the renewable's technologies then nZEB agenda would be achievable in the near future.

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