Ecological Footprint Assessment of Building Materials

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Abstract

Building materials are responsible for huge resource utilizations during the building lifespan, therefore, the study of environmental impact of building materials is very important. This study is evaluated on the environmental impact of different building materials on the planet. The presented approach needs information from the process on energy use and/or carbon dioxide emissions lifecycle analysis (LCA) research and information on agricultural and forestry land are used to calculate the value of a material's Ecological Footprint. The findings in this study can also support and facilitate the discussion of the meaningful targets required to achieve the United Nation Sustainable Development Goals.

Keywords. Building Materials, Ecological Footprint, Sustainability, Environment Assessment, Carbon Emissions.

1. INTRODUCTION

The most significant element impacting natural resource consumption, enormous energy demand, greenhouse gas (GHG) emissions, waste assimilation, etc. is due to urbanization. [1]. Around the world, the construction industry is responsible for about 40% of the material use. [2], approximately 32% of the world's total energy consumption, but only 19% of the GHG emissions related to energy [3]. Indian construction industry's annual growth rate at 5.6% from 2016 to 20; by 2025, it may increase yearly to 7.1% [4]. However, buildings in India utilise one-

third of all the power produced and one-quarter of all the primary energy consumed globally [5].

The usage of building materials (30%), C&D waste production (25%), water use (25%), and land use (12%), of which 10-20% is consumed during the duration of the building, all have an influence on the environment [6]. There have been numerous studies on the use of energy [4,5], greenhouse gas emissions [5], C&D waste creation [10], transportation of building materials and trash [4], and water use [5] in buildings. By 2030, it is anticipated that India will utilise almost 15 billion tonnes of materials, and by 2050, it will rise to 25 billion tonnes. [4].

The environmental impact analysis of construction materials is the main topic of this study. The Ecological Footprint of different types of building materials have been estimated. This study is important because, in the near future, a large infrastructure improvement will be required to improve living standard in India as well as to achieving the vision of 'House to All'. This study will be useful for determining the construction industry's environmental impact and for outlining a strategy for producing sustainable building materials. A study of this kind would be useful in determining how the country's building sector's energy efficiency might be reduced to decrease the ecological footprint on environment.

2. METHODOLOGY

2.1 EF of Building Materials (EF_m)

Building materials have some significant environmental impact. In this study, the EF_m has been estimated based on two parameters: (1) manufacturing impact, (2) natural impact. While extracting materials, neglecting the usage of the land. The EF_m has been calculated by Eq. 1 [1]:

$$EF_m = \underbrace{\sum \left(\frac{(Ci+Ri).Emi}{Af/(1-Aoc)}\right).e_{CO2\,land}}_{\text{Manufacturing impact}} + \underbrace{\sum \left(\frac{Cwi}{Ywi}\right).e_i}_{\text{Natural impact}} \quad (1)$$

2.2 Details of Building Materials

Cement, bricks, steel, aggregates (fine and coarse), glass, aluminium, and other basic materials are taken into consideration.

2.2.1 Cement

Essentially, Portland cement is made of combinations of lime (calcium oxide, CaO) mixed with silica (silicon dioxide, SiO_2) and alumina (aluminium oxide, Al_2O_3). The embodied energy of Ordinary Portland Cement (OPC) is reported as 2.38 MJ/kg to 3.72 MJ/kg for the Indian cement industries [1].

2.2.2 Bricks

Bricks are responsible of significant amount of environmental impact [5]. The comparative environmental impact assessment of different types of bricks should be examined. The details of some general bricks are given in Table 1.

Table 1 The details of different types of bricks and blocks

Building material	**Embodied Energy**	**Remarks**
Fired Clay Brick (230×115×75 mm^3)	1.2 – 4.14 MJ/kg	Clay is main component
Compressed Stabilised Earth Block (CSEB) (Size: 300x150x100 mm^3)	2.75 – 3.75 MJ/block	Clay and sand are main materials
Fly Ash Brick (FAB) (Size: 230x115x75mm^3)	800–4750 MJ/ m^3 of bricks.	60% fly ash, 30% sand, and 10% cement (made of lime and gypsum)
Sun-dried Brick (SDB) (Size: 230x115x75mm^3)	0.033 – 0.187 MJ/1000 bricks	Raw material extraction and manual casting.
Autoclaved Aerated Concrete Block (AAC) (Size: 400x200x200 mm^3)	3.2 - 4.0 MJ/kg	Light weight and low-density block

2.2.3 Steel

Steel reinforcement has been used to enhance the concrete tensile strength. Different grade of steel bars is available in different sizes (diameter) like 8mm, 10mm, 12mm, 16mm, 20mm, 25mm and 32mm. Embodied Energy of steel production is reported as 16.4–34.23 MJ/kg [5].

2.2.4 Aggregate

Rocks that have been crushed are typically used as aggregates in building construction. At 0.04 to 0.083 MJ/kg, aggregates' embodied energy is quite low [3]. The 4.75 mm IS sieve size retained the coarse particles. The ideal coarse aggregate consists of angular-shaped, screened crushed rock that is devoid of organic materials, dust, clay etc. The fine aggregate retained on an IS sieve with 0.075 mm. It should be free of organic debris, loam, and clay, and should be clean screened dusts. The details of size of aggregate mention in Table 2.

Table 2 Details of aggregate size

Types of Aggregates	**Size (mm)**
Coarse aggregate	4.75 mm - 40 mm
Fine aggregate	0.075 mm - 4.75 mm
Filler or Dust	< 0.075 mm

2.2.5 Ceramic Tiles and Granite/Marble Slab

A composition for ceramic tiles that was made from resources including granite and contains the elements listed below, expressed in weight percentages depending on the composition's overall weight: SiO_2 (56–64 wt%), Al_2O_3 (15–17 wt%), K_2O (2–3 wt%), Na_2O (0.5–1.5 wt%), CaO (5–5.7 wt%), MgO (0.5–0.6 wt%), and L.O.I. (7–9 wt%). According to the research, ceramic tile has an embodied energy value of 2.20–14.87 MJ/kg., polished marble and granite stone slabs have an embodied energy of 1.53-2 MJ/kg and 0.01-13.90 MJ/kg, respectively [4,5].

2.2.6 Glass

Glasses are made from sand (silicon dioxide, or SiO2), limestone (calcium carbonate, or CaCO3), and sodium carbonate (Na2CO3). Float glass is believed to have an embodied energy of 7.88 to 15 MJ/kg [5].

2.2.7 Wooden Materials

It is an organic substance made of naturally occurring cellulose fibres, which are strong under tension, embedded in a lignin matrix, which resists compression. Wood has been used to build things like windows, doors, and furniture in construction industry. Embodied Energy of wooden product is reported as 4.60–34.1 MJ/kg.

2.2.8 Insulation Materials

Different natural including minerals, vegetable fibres, animal products, and synthetic substances, are used to make insulation materials. The details of insulation materials are mentioned in Table 3.

Table 3 Embodied energy of insulation materials

Insulation	
Material Description	**Embodied Energy in MJ/kg**
General Insulation	45.00
Cellular Glass	27.00
Cellulose	0.94 to 3.3
Cork	4.0
Fibre glass (Glass Wool)	28.0
Flax (Insulation)	39.5
Mineral Wool	16.6
Paper Wool	20.17
Polystyrene	See Plastic
Polyurethane	See Plastic
Rock Wool	16.80
Wood Wool (Loose)	10.80
Wood Wool (Board)	20.00
Wool (Recycle)	20.90

3. RESULTS AND DISCUSSUON

The building materials manufacture such as cement, bricks, steel, ceramic tiles and insulation materials etc. require a large quantity of natural resources and energy. The small amount of embodied energy (or embodied carbon emissions) in one ton of building material, when used in large quantity in a building, results in construction contributes huge amount of GHG emissions and high constructional Ecological Footprint of building. Therefore, Ecological Footprint of building materials are estimated as follows:

3.1 Cement: Each building material has a vastly different amount of embodied energy (or emissions), especially cement because cement manufacture requires a lot of energy. The EF of cement is estimated as 0.042 – 0.072 gha/ton.

3.2 Bricks: A comparative environmental effect evaluation based on ecological footprint has been estimated in this study since bricks have a considerable ecological impact. Table 4 provides specifics regarding the Ecological Footprint Assessment of ordinary bricks.

Table 4 The details of Ecological Footprint of brick/block

Building material	**Ecological Footprint [6]**	**Remarks**
Fired Clay Brick (230×115×75 mm^3)	0.07 – 0.32 gha/1000 bricks	Density:1800-2400 kg/m^3; (1 m^3 = 600 bricks)
Compressed Stabilised Earth Block (CSEB) (Size: 300x150x100 mm^3)	0.053 – 0.073 gha/ 1000 blocks	--
Fly Ash Brick (FAB) (Size: 230x115x75mm^3)	0.026 – 0.154 gha/ 1000 bricks	--
Sun-dried Brick (SDB) (Size: 230x115x75mm^3)	6.4 x 10^{-7} – 3.6 x 10^{-6} gha/1000 bricks	--
Autoclaved Aerated Concrete Block (AAC) (Size: 400x200x200 mm^3)	6.2 x 10^{-5} – 7.7 x 10^{-5} gha/kg	--

3.3 Aggregates

It is the most voluminous ingredient in most building materials, and it has the highest mixture weight in building construction. The Ecological Footprint of aggregate production is estimated as 0.0008 – 0.0016 gha/ton.

3.4 Ceramic Tiles and Granite/Marble Slab

The Ecological Footprint of ceramic tiles is estimated as 0.04 – 0.29 gha/ton. The EF of polished granite and marble slab is estimated as 0.0002 – 0.27 gha/ton.

3.5 Glass

Glass has an estimated 0.15 to 0.2 gha/ton ecological footprint.

3.6 Wooden product

The Ecological Footprint of wooden product is estimated as 0.11 – 0.69 gha/ton.

3.7 Insulation Materials

Insulation materials come from different sources like minerals, vegetable fibres, animal products, and synthetic compounds. The Ecological Footprint of Insulation materials is estimated as 0.018 – 0.873 gha/kg.

4. CONCLUSION

Construction sector plays very important role in the development of any nation. This construction result in generating the CO_2 emissions and effect the ecosystem of the planet. Materials processing of building materials consume energy resources and manpower and at the same time emersion of CO_2 effect the ecological footprint on the globe. The Ecological Footprint of different construction materials estimated in this study. Ecological Footprint of cement is as 0.042 – 0.072 gha/ton which is important building material in construction. It indicated that the partial replacement of cement in concrete in construction to reduce overall Ecological Footprint of the construction.

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