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Assessment of Embodied Energy and Environmental Impact of Sustainable Building Materials and Technologies for Residential Sector †

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Abstract: The energy demand of developing countries increases every year. Large amounts of energy are consumed during the production and transportation of construction materials. Conservation of energy became important in the perspective of limiting carbon emissions into the environment and for decreasing the cost of materials. This article is concentrated on some issues affecting the embodied energy of construction materials mainly in the residential sector. Energy consumption in three various wall structures has been made. The comparison demonstrated that the embodied energy of traditional wall structures is 3-times higher than the energy efficient building materials. CO_2 emissions produced by conventional materials and green building materials are 54.96 Kg CO_2/m^2 and 35.33 Kg CO_2/m^2, respectively. Finally, the results revealed substantial difference in embodied energy and carbon footprints of materials for which its production involves a high amount of energy consumption.

Keywords: embodied energy; sustainable materials; carbon emissions

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1. Introduction

The rapidly growing global energy consumption over last two decades is alarming and it significantly influenced the energy sector by depleting energy resources [1]. The world's overall energy consumption has increased by 30% during last twenty-five years [2]. The building sector, by utilizing 30 to 40% of world energy resources, stands third in ranking after industrial and agriculture sectors [3]. In January, the 2008 European Commission (EC) formulated a Climate Action Package with the aim to preserve global energy and control Green House Gas (GHG) emissions by increasing the share of renewable energy resources up to 20% by the end of year 2020 [4]. Globally, many residential energy policies are framed for presenting different energy saving programs by signifying numerous potential areas and loop holes [5,6]. As the housing sector is the major consumer of world's primary and secondary energy, suitable energy-efficient strategies are, therefore, required, particularly in this sector.

2. Literature Review

There are many articles on embodied energy of building materials that mainly relate to different methods of assessment, gathering embodied energy of different building materials and examining other features that affect the assessment of embodied energy. Various research revealed that embodied energy can be determined by conducting different experiments or analysis. The report [7] highlighted the factors affecting embodied energy, which includes various boundary conditions for a system. Basbagill, J. [8] shows that operational energy of building consumes 80% of the total energy throughout the life cycle of a conventional building. Mpakati-Gama [9] made a comparison between current data and different approaches for determining the embodied energy and CO_2 footprints of buildings.

Based on the literature review, it is important to find the embodied energy of different materials, especially sustainable materials that could play important roles in reducing building energy and also reducing carbon emissions.

3. Embodied Energy

In building sector, the consumption of energy can be divided into two categories. Energy consumed during mining, transportation, manufacturing process of raw materials, assembling and maintenance is known as embodied energy. Operational energy is the energy required for building during its lifetime from commission to destruction. Embodied energy makes up practically 20% of total building energy.

3.1. Assessing of Embodied Energy

The embodied energy of a building can be assessed through various processes:

- Energy used to transport the raw material on site and number of workers used to build the site;
- Only constructional material or other fittings used in the building such as kitchen or bathroom fitting, etc.;
- Upstream energy inputs for making materials such as factory, lightening or energy used on machine for maintenance and manufacturing materials.
- Embodied energy for urban infrastructure such as roads, drains, water and energy supply.

3.2. Embodied Energy of Basic Building Materials

Cement, lime, glass, steel and aluminum are used as basic building materials. The embodied energy (MJ/kg) and CO_2 ($KgCO_2$/kg) emissions produced are shown in the Table 1.

Table 1. Embodied energy and CO_2 emissions of basic building materials.

Material	EE (MJ/Kg)	CE ($KgCO_2$/Kg)
Cement	4.6	0.83
Lime	5.3	0.74
Glass	15	0.85
Aluminum	155	8.24
Steel	24.4	1.74

4. Results and Discussion

4.1. Conventional Building Materials

Masonry walls are the major energy consuming component of buildings. Different materials are used for walls such as clay brick, hollow blocks, AAC blocks and soil cement block. In this study, the main focus is to compare embodied energy and carbon emissions of different kinds of wall structures during the construction of buildings.

4.2. Embodied Energy of Conventional Building Materials

Conventional clay bricks, low weight hollow concrete blocks and highly thermally insulated Auto Clave aerated concrete blocks are used for building construction. The EE and CO_2 emissions of conventional building materials are shown in Table 2.

Table 2. Embodied energy and CO_2 emissions of masonry materials.

Material	Size (mm)	Φ (Kg/m^3)	EE (MJ/kg)	EE (MJ/m^2)	CE (CO_2Kg/Kg)	CE (CO_2Kg/m^2)
Clay Brick	76 × 29 × 114	1800	3	600	0.22	45.14
Hollow Block	203 × 406 × 114	725	0.95	78.5	0.129	10.66
AAC Blocks	203 × 610 × 114	600	3.5	220.5	0.28	19.15

4.3. Embodied Energy of Sustainable Materials/Technologies

Thermal insulations are used in wall structures to reduce heat losses throughout the year. Thermal insulations used in construction material are shown in Table 3.

Table 3. Embodied energy and CO_2 emissions of thermal insulations.

Material	φ (Kg/m^3)	EE (MJ/Kg)	EE (MJ/m^2)	CE (CO_2 Kg/Kg)	CE (CO_2Kg/m^2)
Expanded Polystyrene	20	109.2	55.47	3.4	1.73
Polyurethane	30	72.1	54.94	3	2.29
Mineral Wool	60	16.6	25.29	1.2	1.83
Fiberglass	12	28	8.53	1.35	0.41

4.4. Case 1: Clay Brick Walls with Thermal Insulations

Total embodied energy and carbon emission produced for different wall structures are calculated in this section and shown in Table 4.

Table 4. Total embodied energy and CO_2 emissions of brick wall structure.

Material	Thickness (mm)	EE (MJ/Kg)	EE (MJ/m^2)	CE (CO_2Kg/Kg)	CE (CO_2Kg/m^2)
Clay Brick	114	3	600	0.22	45.14
Internal Plaster	20	1.55	58.9	0.213	8.09
External Plaster	20	1.55	58.9	0.213	8.09
Polystyrene	25	109.2	55.47	3.4	1.73
Polyurethane	25	72.1	54.94	3	2.29
Total (1–4)	179	115.3	773.27	4.05	63.05
Total (1–3 and 5)	179	78.2	772.74	3.65	63.61

4.5. Case 2: Hollow Concrete Block Wall Structure with Thermal Insulation

In this section, embodied energy and carbon emissions of hollow concrete block wall structure are calculated and detailed shown in Table 5.

Table 5. Total embodied energy and CO_2 emissions of hollow block wall structure.

Material	Thickness (mm)	EE (MJ/Kg)	EE (MJ/m^2)	CE (CO_2Kg/Kg)	CE (CO_2Kg/m^2)
Hollow Block	114	0.95	78.5	0.129	10.66
Internal Plaster	20	1.55	58.9	0.213	8.09
External Plaster	20	1.55	58.9	0.213	8.09
Polystyrene	25	109.2	55.47	3.4	1.73
Polyurethane	25	72.1	54.94	3	2.29
Total (1–4)	179	113.25	251.77	3.95	28.57
Total (1–3 and 5)	179	76.15	251.24	3.55	29.13

4.6. Case 3: AAC Block Wall Structure with Thermal Insulation

In this section, embodied energy and CO_2 emissions of AAC block wall structure with thermal insulation are calculated and brief detailed shown in Table 6.

Table 6. Total embodied energy and CO_2 emissions of AAC block wall structure.

Material	Thickness (mm)	EE (MJ/Kg)	EE (MJ/m^2)	CE (CO_2Kg/Kg)	CE (CO_2Kg/m^2)
AAC Block	114	3.5	220.5	0.28	19.15
Internal Plaster	20	1.55	58.9	0.213	8.09
External Plaster	20	1.55	58.9	0.213	8.09
Polystyrene	25	109.2	55.47	3.4	1.73
Polyurethane	25	72.1	54.94	3	2.29
Total (1–4)	179	115.8	292.15	4.106	37.06
Total (1–3 and 5)	179	78.7	291.68	3.706	37.62

Total embodied energy and carbon emissions for clay brick wall structure are higher than the other two wall structures. The hollow block has the lowest embodied energy because of its raw material and manufacturing process. The AAC block has much higher embodied energy, but it is more suitable due to its low thermal conductivity and high bearing strength. Table 7 gives the detailed information about EE and CO_2 emissions of various wall structures.

Table 7. Total embodied energy and CO_2 emissions of all wall structures.

Material	Total EE (MJ/m^2)	Total CE (Kg/m^2)
Clay Brick	718	55
Hollow Blocks	197	27
AAC Blocks	339	36

5. Conclusions

The current study deals in depth with assessment of embodied energy and carbon footprints of various building materials. Comparison between various wall structures indicates that conventional building materials such as clay brick have higher embodied energy and also produce higher amount of carbon emissions. For energy efficiency and environmentally friendly conditions, AAC blocks are used as sustainable materials for buildings. With the integration of thermal insulation materials on different wall structures, energy consumption can be reduced. A residential building contains normal 1000 GJ of energy embodied in material utilized in construction that is equivalent to right around 15 years typical operational energy.

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