Assessment of Embodied Energy for an Institutional Building

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ABSTRACT: Today, developing nations are witnessing an unprecedented pace of urbanization in the wake of industrialization and globalization. This is giving rise to an ever increasing demand for housing and infrastructure to support the growing population and its activities. Embodied energy is the energy in total needed in manufacturing and extracting the raw materials, energy consumed for transportation and the external energy applied to raw materials in producing or assembling the final product. In this project, Energy accounted in different material used for construction of this building is calculated. All the material used for construction is accounted and Embodied energies of different materials has been worked out. The Embodied energy calculation arrived based on energy consumed for production and Transportation. With the estimated total quantity of all the materials and the energy, an analysis about the major contributors of embodied energy has been studied and comparisons have been made across different materials between the production and transportation energies. The values have been normalized and a tool has been made on a platform called Spyder to generate the embodied energy calculation for the provided inputs. Suitable alternative material, which consumes less Embodied energy is suggested.

KEY WORDS: Embodied energy; Production energy; Transportation energy; Alternative.

I. INTRODUCTION

Over the last decades the term sustainable development has been one of the most discussed topics in our society. In one hand, there is a demanding concern with environmental issues in order to preserving the Earth for the future generation, but also for the next ones. On the other hand, the population growth is expected to increase rapidly in the near future. Between 2011 and 2050 it is estimated an increase of 2.3 billion people (United Nations, 2014). In consequence, the social and economic activities will become more competitive. Associated with the population growth is associated a larger consumption of water, food, energy, and materials and higher values of waste production and CO2 emissions. Currently, more than half of world’s population is living in cities and more and more people are expected to migrate from the rural areas to the urban areas.

II. SCOPE OF THE PROJECT

The embodied energy emitted from the buildings is an emerging concern with respect to environmental sustainability. There are several practices that could be adopted to minimize this energy, either with respect to the production energy or with that of the transportation energy. In this project, the materials involved in the construction are listed out and their quantities are determined. Assessment of quantities is an important step in the evaluation of embodied energy. The standard production energy coefficients of these materials are calculated and referred. The coefficients are multiplied with the quantity of that material to calculate the production energy of that material. Next by, the energy emitted by the burning of fuels while transporting the materials from the manufacturing plant to the site of construction is measured by taking the mileage of the vehicle that is used for construction, the number of trips made and the distance into consideration. Several comparisons have been made between the production and transportation energy to study about the major contributors of embodied energy. Also a tool is developed on a platform called “SPYDER” to assess the embodied energy for any building by providing a few inputs. This would be useful to take precautionary measures. Also the major contributor is replaced with a suitable alternative material with their embodied energy calculation proving to be more efficient than its former.
III. EXPERIMENTAL PROCEDURES

OBJECTIVES
- Analyze and list the materials that are used in the construction of an institutional building and those contribute to embodied energy.
- Compute the production and transportation energies of those materials.
- Based on the results of analysis, alternate material is suggested and a tool for evaluation of embodied energy is established.

Formulae
- Embodied energy = Production energy + Transportation energy
- Production energy = Production energy per unit x Total quantity
- Transportation energy (1) = Total distance/3 X 45.5

EMBODIED ENERGY
Calculation for brick
Material – Brick
Uses in building – Used in construction of wall
Quantity estimation
Weight of 1 brick = 3.5 kg
Total number of brick = 793136
Total Quantity = 2775976 kg

Production process:
- No of bricks fired in one batch = 20,000 Bricks
- Average of weight of fired brick = 3.21 kg
- Total weight of fired batch = 64,200 kg
- Type of fuel = Wood
- Weight of fuel used in one batch = 12,000 kg
- Calorific value of fuel = 15.54 MJ/kg
- Total energy input = Calorific value of fuel * Weight of fuel used = 186,516 MJ
- Specific Energy consumption = Total energy input/weight of fired batch
- Specific energy consumption = 2.91 MJ/kg fired brick

Transportation energy
Place of acquiring: Thirukurathupalli
Distance = 20.2 kms ~ 22 kms
Transportation energy = 333.6 MJ/Kg

Calculation for cement
Material - Cement
Uses in building – It is used in mortar for plastering, masonry work, pointing etc. It is used in concrete for laying floors, roofs and construction lintels, beams, stairs etc…

Quantity estimation
BEAM
Beam size = 0.3x 0.6 m
Beam volume = 661.072 m³
Total quantity of cement = 403.21 x 661.072 = 266544.23 kg

COLUMN
Column 1 size = 0.3 x 0.25 m
Column 2 size = 0.23 x 0.3 m
Volume of column = 176.175 m³
Total quantity of cement = 403.2 x 176.175 = 71033.76 kg

SLAB
Slab thickness = 0.15 m
Slab volume = 283.68 m³
Total quantity of cement = 403.2 x 283.68 = 1143709.04 kg

WALL
Wall thickness = 0.23 m
Volume of wall = 1788.76 m³
Volume of openings = 202.489 m³
Total volume of wall = 1586.271 m³
For masonry wall taking ratio as 1:5
Volume of cement = 133200 kg
Total quantity of cement = 1481379.53 kg

Calculation for transportation
Total transportation energy = Quantity x Transportation energy per unit
= 2775976 x 0.025
= 69399.4 MJ

Embodied energy calculation
Production Energy - 2.91 MJ/kg
Transportation Energy - 0.025 MJ/kg
Energy per brick - 2.935 MJ/kg
Weight of 1 brick - 3.5 kg
Total number of bricks - 793136
Total Quantity - 2775976 kg
Total Embodied Energy – 8147489.56 MJ
Production energy of cement = 2.85 MJ/kg

**Transportation energy calculation**

Place of acquiring: Ariyalur
Distance: 49.2 ~ 50 kms (approx.)
Transportation energy = \( \frac{50}{3} \times 45.5 = 758.3 \text{ MJ/Kg} = 758.3/13,000 = 0.0583 \text{ MJ/Kg} \) for each trip

Total transportation energy = Quantity \times Transportation energy per unit

= 266544.23 \times 0.0583 = 15539.5 \text{ MJ}

**Embodied energy calculation**

Production Energy - 5.85 MJ/kg
Transportation Energy - 0.0583 MJ/kg
Energy per kg of cement - 5.90 MJ/kg
Total Quantity - 1481379.53 kg
Total Embodied Energy - 8740139.22 MJ

**Calculation for coarse aggregate**

Material – Coarse aggregate
Uses in Building: It is used in concrete for laying floors, roofs and construction lintels, beams, stairs etc.

**Quantity estimation**

**BEAM**
Beam size = 0.3 x 0.6 m
Beam volume = 661.072 m³
Quantity of coarse aggregate = 661.072x1310= 866004.32 kg

**COLUMN**
Column 1 size =0.3 x 0.45 m
Column 2 size =0.23 x 0.3 m
Volume of column =176.175 m³
Quantity of coarse aggregate= 176.175x1310= 230789.25 kg

**SLAB**
- Slab thickness = 0.15 m
- Slab volume = 2836.58 m³
- Quantity of coarse aggregate = 2836.58 x 1310 = 3715919.8 kg

Total quantity of coarse aggregate = 4812713.37 kg

**Production process**
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SLAB
• Slab thickness = 0.15 m
• Slab volume = 2836.58 m³
• Total quantity of sand = 2836.58 * 672 = 1906181.76 kg

Production energy = 0 MJ/Kg

Transportation energy calculation
Place to be acquired: Trichy
Distance: 39.3 kms ~ 40 kms
Transportation energy = 606.6/13000 = 0.0466 MJ/Kg for each trip
Total transportation energy = Quantity x Transportation energy per unit = 11501.42 MJ

Embodied energy calculation
Production Energy - 0 MJ/kg
Transportation Energy - 0.0466 MJ/kg
Energy per kg of sand - 0.0466 MJ/kg
Total Quantity - 246811.74 kg
Total Embodied Energy = 11501.427 MJ

Calculation for steel
Material - Steel
Uses in building: It is used in reinforcements of beams, columns, slab.

Quantity Estimation
BEAM
Total quantity of steel = 661.072 * 120 = 79328.64 kg
COLUMN
Total quantity of steel = 176.175 * 120 = 21141 kg
SLAB
Total quantity of steel = 2836.58 * 100 = 283658 kg
Total quantity of steel = 384127.64 kg

Production process

Calculation for glass
Material - Glass
Uses in building: It is used in windows of the building.
Quantity estimation
Total weight of glass = 3184 kg

Production process
Production energy = 25.8 MJ/kg

Transportation process

Place of acquiring: Chennai
Distance = 364 kms ~ 370 kms
Total transportation energy = Quantity x Transportation energy per unit
= 3184 kg x 0.4316 = 1374.2 MJ

Embodied energy calculation
Total Quantity = 3184 kg
Total Embodied Energy = 83521.414 MJ

Calculation for Aluminum

Material – Aluminum

Uses in building: Partitions for segmentation

Quantity assessment: Aluminum partitions (5 kg/sq.m)
Total Weight of Aluminum = 1450 kg

Production process

Manufacturing process of aluminum

Melted and refining
Treatment in float bath
Coating
Annealing
Inspecting
Cutting

Production energy = 236.8 MJ/kg

Transportation energy

Place of acquiring: Madhavaram
Distance = 365.5 kms ~ 370 kms
Total transportation energy = Quantity x Transportation energy per unit
= 1450 kg x 0.4316 = 625.82 MJ

Embodied energy calculation
Total Quantity = 1450 kg
Total Embodied Energy = 343985.82 MJ

Calculation for Galvanized iron

Material – Galvanized iron

Uses in building: Used in exhaust pipe fittings and in vents

Quantity estimation
Exhaust in restrooms
Total weight = 3750 kg

Production process

Manufacturing process of pig iron
Collection of pig iron
Treatment in blast furnace
Separation of molten iron
Galvanizing of iron

Transportation energy

Place of acquiring: Dharapuram
Distance = 222 kms ~ 230 kms
Total transportation energy = Quantity x Transportation energy per unit
= 1005 MJ

Embodied energy calculation
Total Quantity = 3750 kg
Total Embodied Energy = 92880
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Calculation for Timber
Material - Timber
Uses in building: It is used in windows and doors of the building

Quantity estimation
Dimension of pane of window= 1.82 x 0.52 m
Total volume of timber for windows = 27.7 m³

Doors
Total volume of timber = 31 m³
Total weight of timber = 22,000 kg

Production process

Calculation for PVC Pipes
Material – PVC
Use in building: Piping and plumbing works.

Quantity estimation
Gent’s restroom
Total weight of pipe in Gent’s restroom = 4680.315 Kg

Ladies restroom
Total weight of pipe in Gent’s restroom = 3762.04 Kg
Total weight of PVC pipe = 8441.34 Kg ~8700 Kg (with miscellaneous additions)

Production energy = 67.95 MJ/Kg

Transportation energy calculation
Place of acquiring: Tirunelveli
Distance = 337 kms ~ 340 kms
Total transportation energy = Quantity x Transportation energy per unit = 8700 x 0.396 = 3445.2 MJ

Embodied energy calculation
Total Quantity = 8700 Kg
Total Embodied Energy = 594610.2 MJ

RESULTS AND DISCUSSIONS
Production energy analysis
Despite the fact that the production energy of Aluminium is comparatively higher than that of others, on mass analysis it does not majorly contribute to energy released.

On the similar pattern, due to the quantity of coarse aggregate that is used, the transportation energy is more. But due to the very less production energy it is counter balanced.

With that the major contributor of energy to the surroundings is from Steel, while suggesting replacement for materials that are major contributors, there is no viable replacement for steel.

Thereby next significant contributor brick can be replaced by fly ash bricks.

Calculation of embodied energy for fly ash bricks

Size of fly ash brick = 0.23 x 0.11 x 0.07 m
Total Quantity = 2.6 x 689413 = 1792473.8 kg

Production energy = 0.89 MJ/kg

Transportation energy calculation

Place of acquiring: Trichy
Distance = 45 kms
Total transportation energy = Quantity x Transportation energy per unit
= 1792473.8 x 0.0525 = 94104.8 MJ

Embodied energy analysis

Total Quantity = 1792473.8 Kg
Total Embodied Energy = 1689406.5 MJ

Energy comparison between brick and fly ash brick

IV. CONCLUSION

In this project an extensive quantity analysis and embodied energy analysis has been done for all the materials involved in the construction of an institutional building. The results showed us the major contributors of energy. Taking that into consideration and in the aim to reduce the embodied energy alternative material to a major contributor has been suggested without impacting the structural strength too. Thereby, conventional bricks are replaced by fly ash bricks which have considerably reduced the embodied energy to about 79.26%. Also a custom embodied energy calculator has been designed based on the results obtained, using a tool named “SPYDER”. This can be used as a tool to calculate the embodied energy involved in the construction prior to the commissioning of the work.

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